4. SAFETY ANALYSIS

A. CRYOGENIC SYSTEM

A.1. System Description

The Cryogenic System and its operation are best described by the Process and Instrumentation Drawings (P&IDs). As mentioned in Chapter 3.Q, there are 404 of these drawings. A representative group have been appended to this report to show the major components and their relationships. If one is unfamiliar with the RHIC Cryogenic System it would be useful to read the first three pages of the Cryogenic Section of the RHIC Design Manual before starting with the P&IDs. This group of drawings may best be entered through the Overall System Block Diagram, RD3A995006, which refers to the other major drawings and depicts their relative positions in the system. Keeping in mind the functions described in the Design Manual, one can follow the flow paths through the P&IDs.

The system is designed, of course, to handle the steady state operating conditions for the two rings. It will be able to cooldown both rings in about one week. When the occasion arises that requires repair of some ring component, it is possible to warm up a single sextant, do the repair and cool that sextant back to operating temperature and, during all that period, maintain the other eleven sectors at or near the design operating temperature.

The details of the design for each of the major subsystems are contained in the Final Design Report for that subsystem. These reports document the design criteria, a summary of the design features, procurement/fabrication plans, testing and installation plans, pre-operations testing plans and a summary of all pertinent documentation for the subsystem. The Final Design Report(s) for each subsystem will be part of the QA file which is retained for the life of the accelerator.

Background Data: The background data sources shown previously in Table 3-Q-3 were used in this analysis of the safety aspects of the Cryogenic System design, fabrication, installation and operation.

Except for the Collider Tunnel, all of the buildings in which the Cryogenic System equipment is housed are classified for ordinary or general industrial usage. Under this classification, the travel distance to an exit in a sprinklered building, such as the Cryogenic, Compressor and some Service

Buildings, is 250 ft (NFPA 101, para. 28.2.6.1 and para. 28.2.4.1), and in an unsprinklered building 200 ft. The travel distance in the Refrigerator Building is 100 ft and 60 ft in the Compressor Building (See Appendix 2, p. 59 & 60). The Service Buildings, although smaller in size, all have multiple exits and easily meet the Code requirements. All of the cryogenic buildings, therefore, meet these requirements. They also are in compliance with the other aspects of NFPA 101.

A.2 Hazard Analysis - Normal Operation

The Project policy for the safety review of cryogenic systems is contained in RHIC OPM 5.5.2.1. The P&IDs and the Active Components List, mentioned above in Chapter 3, Section Q.5., were the basis for two Failure Modes and Effects Analyses (FMEAs) which were done for this system (see Appendix 6). The first analysis was conducted for the Normal Operating Condition, when the rings were cooled to 4K for steady-state operation. The second analysis was conducted for a single sextant warm-up, where one or more magnets required removal and replacement. In this case, RHIC operations would prefer to maintain the remainder of the machine at 4K to save energy and reduce recooling time. A warm-up of the 3 o'clock sextant was analyzed, and is representative of a warm-up of any other sextant. These analyses list the identified hazards which may result from the failure of each item of equipment in the system and assess the risk of each event. Where an analysis resulted in action items recommended to eliminate or control the hazard, these items have been incorporated into the design.

The Normal Operations FMEA was performed in conjunction with the design effort for the Cryogenic System Valve Boxes. The Cryogenic System Valve Boxes are the centralized controls for the distribution of cryogen at the end of each sextant. At the 6 o'clock junction, the Cryogenic System Valve Box functions were expanded to include the interface between the RHIC Refrigerator and the Collider Rings and the helium circulators. The system makes extensive use of remotely operated valves which may be controlled from the Cryogenic System Main Control Room. These valves are air-operated via solenoid controls, with the de-energized state relying upon spring force for motive power. Thus, an initial de-energized state must be assigned in order to conduct the analysis. When RHIC is in operation, the Cryogenic System will remain in the cold state for a major part of the year, with, at most, annual shut-downs for maintenance. Therefore, initial valve state was chosen such that failures of the valves will not cause an interruption of Collider operations.

The analysis of Normal Operations was especially successful in discovering some initial design flaws which would have prevented intended operation of the Cryogenic System. These flaws were corrected prior to valve box construction, with negligible impact on system cost or schedule. The FMEA worksheets provide details regarding the failure modes and failure effects for each Cryogenic System Valve Box component. Also included in the FMEA was an analysis to determine the means by which the failure could be detected.

Eighty-three functionally-distinct categories for 1880 components were analyzed. In these 83 categories, no single-point failures would result in personal injury or major system damage. Failures in 27 functional categories of components would restrict or inhibit cryogen flow to a degree that, for a worst case situation, the magnets would be insufficiently cooled and might quench. However, all magnets are capable of withstanding a quench. The large DX magnets have a system of quick-acting heaters which will drive an entire magnet normal whenever a local quench is detected, assuring that the energy of the collapsing magnet field is distributed over the whole magnet. All of the other superconducting magnets are intrinsically self-protecting. Pressure transducers for the Cryogenic System have a capacity at least equal to the Cryogenic System design pressure of 275 psi. Failures in nine functional categories of components have the potential to cause loss of helium gas inventory. The worst case failure assumes no intervention. However, a sizable gas leak would be readily detected by Cryogenic System Operators who are trained to prevent any significant loss of helium inventory using the system's instrumentation/controls; i.e., pressure transducers, temperature sensors, remote valve operation, etc.

Failures in four functional categories of components may affect the speed control for the cryogenic circulators. Two failures would cause the speed to decrease, with a potential for reduced cooling capacity. Two others could command speeds excessive for the circulators. To prevent electrical overspeed of the circulators, separate overspeed protection circuits were incorporated. In addition, two faults could cause magnets to de-energize due to loss of power lead cooling. One of these faults involves the status of a manual valve, which would be detected on start-up. Five faults could cause an imbalance of the refrigerator. A significant imbalance in the refrigerator would cause the refrigerator to be shut off from the rings in order to stabilize refrigerator operation. This shut off is not hazardous, because the rings would act like a large dewar, taking several hours to warm sufficiently before the pressure would reach relief valve settings. Two faults could cause valves to not seat entirely, permitting leakage of gas. These faults would have no impact on Normal Operations. Finally, failures of relief valves could result in the overpressure of piping or adjacent components which may contain cryogen. These relief valves protect the volume between two valves in each sextant which interconnect adjacent process lines. An overpressure can only occur when these volumes are filled with cryogen, then warmed with the valves closed. However, one of the valve pairs is normally open, thereby venting the volume to a process line. These volumes also have pressure sensors. These valves and the volumes reside inside the valve box vacuum tanks which provide containment. There is no hazard from helium release because of the small volume of gas involved.

A.3. Hazard Analysis - Single Sextant Warm Up

Similarly, a FMEA was conducted for a single sextant warm up. The analysis considered both rings being warm in the affected sextant, although it likely that only one ring would require warming. Because the rings are mirrored configurations, the analysis for one ring is applicable to the other. Warming the sextant is a transient operation lasting less than 24 hours, during which period operations will be conducted to maintain the remainder of the sextants at about 4 K. These operations consist of two modes – one to maintain the heat shield, and the second to circulate 4 K gas to keep the other sextants cold. The two operations are independent. The FMEA considers both modes in a single tabulation of those components which would have an impact on one or the other mode. A majority of the components in RHIC are not involved in the warm-up operation or do not interface with the warmed-up sextant and, thus, have no impact on the operating state.

Ninety-four functionally-distinct categories for 1880 components were analyzed for this FMEA. There are no single-point failures which would result in personal injury or major system damage. Twenty-eight functional categories of components would restrict or inhibit cryogen flow to a degree that, for a worst case situation, the magnets would be insufficiently cooled. The consequence is that the temperature rise would be accompanied by a pressure rise and the need to store helium inventory. This can be accomplished safely in the liquid storage area or in the gas storage tanks. Failures in ten functional categories of components have the potential for loss of helium gas inventory, with three additional categories posing a potential thermal and/or Oxygen Deficiency Hazard to personnel as well as the loss of inventory. The worst case gas leak assumes no intervention. However, a sizable gas leak would be readily detected by Cryogenic System Operators, who are trained to prevent any significant loss of helium inventory using the system's instrumentation/controls; i.e., pressure transducers, temperature sensors, remote valve operation, etc. The three faults which could result in the potential for personnel hazard involve the process isolation valves between the warm and cold sextants. The fault assumes the valves are open. This fault is unlikely, as the valves are lockable, and were designed as such because this failure mode was obvious.

Ten faults could cause an imbalance of the refrigerator. The consequences of an imbalance in the refrigerator and the failure of relief valves are similar to those described above.

A.4. <u>Liquid Storage System - Description</u>

Three (3) 11,000 gallon dewars provide a storage volume for Liquid Helium (LHe) for the RHIC system. Each LHe dewar contains a Differential Pressure Transducer (DPT) for liquid level indication along with a force transducer. Readings from both instruments are available through the cryogenic computer control system. The LHe volume of each dewar is protected from overpressurization by use of a dual branch pressure relief valve and burst disk configuration. A 3-way ball valve is used to connect the dewar to either one branch or the other. In the event of a relief valve failing to reseat or a burst disk opening, that branch can be isolated to minimize the loss of helium without loss of overpressure protection. Vacuum indication is available locally.

Dewar #1 and Dewar #2 are made by Cryenco and Dewar #3 by Gardner. The Cryenco dewars each include a small, self-contained LN_2 dewar. Dewar #3 does not have an independent LN_2 dewar and relies upon an external LN_2 storage dewar. The Cryenco self-contained LN_2 dewars have DPTs to monitor liquid levels. Overpressure protection is provided by pressure relief valves in parallel with a check valve. The LN_2 dewars are insulated by vacuum vessels and protected by pressure relief valves. The pressure in the LN_2 shield of the Gardner dewar is controlled by a float, and overpressure is vented to atmosphere by two (2) check valves in parallel. The Cryenco dewars have internal electrical heaters in the LHe vessel. The Gardner dewar has a heat exchanger in the LHe vessel which is not expected to be used by the system. Each dewar uses a burst disk (Cryenco at 5 psig, Gardner at 0.25 psig) for vacuum vessel overpressure protection.

A 20,000 gallon Cryenco LN_2 dewar (Dewar #4) provides LN_2 for shielding the LHe dewars. This dewar is also protected from overpressure by use of a dual branch pressure relief valve and burst disk configuration. A 3-way ball valve is used to connect the dewar to either one branch or the other as in the LHe dewars. The LN_2 tank is enclosed by a vacuum vessel. The dewar uses dual burst disks (at 10 psig) for vacuum vessel overpressure protection. A DPT is used for liquid level indication, available through the cryogenic computer control system. Pressure indication is also available through the cryogenic computer control system, and vacuum and nitrogen pressures are available locally. A series of manual and digitally controlled pneumatic valves allows LN_2 to feed the LHe dewars as well as LN_2 dewar operations. The LN_2 header can be isolated at both the outlet of the LN_2 dewar and the inlets of the LHe dewars.

Each LHe dewar is connected to cryogenic system Supply (S), Cooldown Return (CR) and Return (R) at the 6:00 VJRR. These headers have been designed to the same operating pressure as the cryogenic system. Relief valves are used for overpressure protection. The Return header is configured so that, at each LHe dewar, gaseous flow can be at the top, branched off the same port as the Cooldown Return, and liquid flow at the bottom, identified as LHe. Digitally controlled pneumatic valves provide isolation for each line at both the VJRR and at each dewar. At the isolation valve at the VJRR, each line has temperature indicators on either side of the valve and a pressure indicator (available through the cryogenic computer control system) on the LSA-side of the valve. At the VJRR, digitally controlled valves allow cross flow between the Return/LHe header and the Cooldown Return header or the Supply header. The Supply header has a Venturi flow meter to measure the amount of flow to or from the Supply header to the LSA. The Supply header can also be cross connected by use of digitally controlled valves with the Cooldown Return header at Dewar #1 and Dewar #2.

A.5. Safety Analysis

All piping and dewars associated with the LSA were examined for protection from overpressure. The primary volume of each of all four (4) dewars has a dual branch, redundant pressure relief valve and burst disk configuration. A 3-Way valve can be used to isolate one branch at a time, but it can not isolate both branches simultaneously. All factory set relief valves and burst disks are properly labeled. Adjustable relief valves have been factory tested and the adjustment mechanism safety-wired.

The cryogenic piping headers (Supply, Cooldown Return and Return/Liquid Helium), which are subjected to the 275 psi operating pressure of the cryogenic system, are designed for that pressure and are protected by at least one pressure relief valve in all possible valve positions and system configurations. These headers are isolated under normal system operations by pneumatically operated control valves. In the event of an overpressure and a failure of a relief valve to open, which is not a typical failure mode, the characteristic of these valves under high differential pressures is to unseat.

Pressure gauges, Differential Pressure Transducer and Pressure Transducers can be isolated from the system in a way that overpressure can develop. The safety concern would be if the piping could catastrophically rupture under these conditions. These components are not isolated during normal operation, where they are protected from overpressure. Isolation of these components would only be for specific testing or replacement. These components are attached to the system using copper piping and threaded fittings. The typical failure mode for these components under high pressure is to leak, typically through soft material such as bellows in the instruments or piping, thereby also reducing pressure. In addition, the high pressure would also be relieved by ruptures in the pipe or leaks through the threaded fittings. Since the volume of helium gas in the instrument piping has been minimized, the risk of injury or damage from overpressure in these lines is low.

Each Dewar contains level and pressure indicators which can be read at cryogenic control stations. The LHe dewars also have pressure/weight transducers for inventory control. These redundant systems mitigate the risk of overfilling, causing a release of a cryogenic hazard (personnel/equipment contact with very cold temperatures). The relief valves of all dewars vent to open atmosphere, so no Oxygen Deficiency Hazard (ODH) condition would be present. Only the pressure relief valves for the Supply, Cooldown Return and the Return/LHe distribution header are located in the VJRR. Since the volume of piping is significantly less than that of the cryogenic system, (which also has its relief valves in the VJRR), no ODH risk would result if the relief valves would vent as long as normal ventilation is present. Dewar overpressure protection includes a 3-way valve which can isolate one branch in the event of a burst disk rupture or a pressure relief valve failure to reseat. This will minimize the release of cryogenic fluids as well as reduce loss of inventory. All remotely operated valves, including valves isolating the dewars from the distribution headers and the distribution headers from the primary cryogenic system (at the VJRR) are pneumatically operated valves which will close (normal state) upon the loss of control signal or pneumatic pressure.

Ninety-two (92) items were analyzed to have a routine risk, as defined by ES&H Standard 1.3.3. These would result in degraded system performance and maintenance actions. Ninety-four (94) items were identified as having a low risk. These items would have either the potential, in the worst case scenario, to release cryogenic fluid, possibly resulting in personnel injury or equipment damage or overpressurizing components. The release of cryogenic fluid would be into open atmosphere so no oxygen deficiency hazard would exist. These areas are not typically occupied and the direction of venting is designed so that the probability of personnel injury is minimized. Overpressurization of components would require a minimum of two independent failures. The following is a breakdown of the low risk items.

Fourty-one (41) items involve failure of components, such as vent and fill valves, which would cause the release of cryogenic fluid. These failures include the loss of insulating vacuum of the He dewars (which would cause a dynamic venting through relief valves), failure of relief valves or insulation valves to close, overfilling the dewar and failure to vent a dewar while filling.

Twenty-six (26) items involve overpressure of components. All sections of piping are protected from overpressure from an unisolatable relief device (either relief valve or burst disk). Two independent failures, one causing the overpressure condition, and second a failure of the relief device would be required to cause damage.

Twenty-five (25) items involve failure of control or isolation valves which could lead to the undesired transfer of fluid and the overfilling of a dewar. All dewars have level gauges and the He dewars also have weight transducers to indicate the amount of LHe in them. In the event that the undesired flow was not detected and allowed to overfill a dewar, pressure relief valves and burst disks would protect the dewar.

Two (2) items involve the electric heaters found in Dewar #1 and #2. These heaters provide a means of adding heat, therefore pressure in the dewars to aid in liquid transfer. A failure in the heater control could result in the overpressure of the dewar. The dewars are protected by relief valves and burst disks. In the current configuration of the LSA, these heaters are not used. Pressurization of a dewar for make up fluid will use pressure from stored gaseous helium.

A.6. Oxygen Deficiency Hazard (ODH)

Mechanisms exist which could result in the release of helium into the Collider Tunnel, Service Buildings housing valve boxes and associated cryogenic system equipment, and the buildings housing the refrigerator and helium compressors. As shown in Table 4-A-2, there also is the potential for the release of nitrogen into the Compressor and 6 o'clock Service Buildings. The quantity and release rate for each gas at each location is dependent upon many variables. Postulated worst-case release rates are presented in Table 4-A-2, along with building volumes and ventilation rates. This table shows that the inert gas release rates can exceed the ventilation rates, thereby displacing air. Likewise, failure of the ventilation system will rapidly cause a hazardous level air displacement. Hence, oxygen deficiency is the potential hazard. While there is no code, regulation or standard directly applicable to these facilities for this hazard, the Occupational Safety and Health Standard for Permit-required confined spaces (29CFR1910.146) defines an oxygen deficient atmosphere as an "atmosphere containing less than 19.5 percent oxygen by volume." Actual physiological effects from an oxygen deficient atmosphere do not begin until concentrations reach 17 percent oxygen by volume (RHIC OPM 5.2.2.4.1).

The RHIC Project issued a policy on Oxygen Deficiency Hazards (ODH) modeled on the standard in use at the Fermi National Accelerator Laboratory. This Policy is contained in RHIC OPM 5.2.2.4.1. Calculations were performed in accordance with this Policy to determine the ODH classifications for each of the potential ODH sites within RHIC (see Appendix 7). This analysis uses the parameters from Table 4-A-2.

TABLE 4-A-2

Oxygen Deficiency Hazard Classification of RHIC Buildings During Normal Operations

Bldg. No.	Building Name	Bldg. Vol. Cu. Ft	Fan CFM	Occup. ManD/D	Peak He SCFM#	Peak N_2 SCFM#	ODH Class*
1005H	Compressor Bldg.	250,000	100,000	0.1	8,000	1,500	0
1005S	Refrigerator Bldg.	240,000	50,000	0.3	27,000	0	1
1005E	Power Supply/Croyogenic Bldg.	TBD	TBD	TBD	TBD	TBD	TBD
1001	Collider Tunnel - 1:00	310,000	60,000	0	150,000	0	0
1003	Collider Tunnel - 3:00	300,000	60,000	0	150,000	0	0
1005	Collider Tunnel - 5:00	390,000	60,000	0	150,000	0	0
1007	Collider Tunnel - 7:00	400,000	60,000	0	150,000	0	0
1009	Collider Tunnel - 9:00	320,000	60,000	0	150,000	0	0
1011	Collider Tunnel - 11:00	300,000	60,000	0	150,000	0	0
1002B	2:00 Support Bldg.	70,000	32,000	0.1	17,000	0	0
1004B	4:00 Support Bldg.	113,000	44,000	0.1	17,000	0	0
1006B	6:00 Support Bldg.	85,000	32,000	0.1	17,000	1,500	0
1008B	8:00 Support Bldg.	75,000	32,000	0.1	17,000	0	0
1010A	10:00 Service Bldg.	110,000	22,000	0.1	17,000	0	0
1012A	12:00 Service Bldg.	110,000	22,000	0.1	17,000	0	0

*Classes per RHIC Project Safety OPM 5.2.2.4.1, "Oxygen Deficiency Hazards (ODH)."
#ODH calculations were based on the integrated time dependent release.

An independent OSHA expert, Hayes Environmental Services Inc., was contracted to review the status of the cryogenic system with respect to the Federal regulations. The complete report is in Appendix 29. The consultant concluded that the OSHA standards do not apply. In summary, the following points were made in the report:

1. The Collider tunnel is not a Confined Space and, as such, the OSHA Confined Space Standard does not apply.
2. The OSHA rules address “normal and foreseeable and actual conditions” and, therefore,
3. Catastrophic failures need not be considered with respect to the need for OSHA required safety systems (they are not “normal and foreseeable and actual conditions”). The cryogenic system is analogous in industry to a gas producer or petrochemical refinery. The system was built and tested to the ASME Boiler and Pressure Code. Therefore, although the possibility exists that an oxygen concentration could go below 19.5% in a low probability catastrophic pipe failure, it would not result in a noncompliance with the law.

In support of the calculations (Appendix 7) that show the RHIC ODH Class 0 areas remain Class 0 below 50 K with PASS and emergency fans in operation and above 50 K without PASS, a helium spill test was conducted on April 17, 1999. The test strongly supported the calculations published in Appendix 7.

The test in support of calculations above 50 K involved the venting of approximately 21,000 SCF of helium gas that was released over a period of about 30 minutes (see Figure 4-A-1). Throughout the test, the emergency ventilation fans were disabled. Note that 50% of the helium was released in the first 3 minutes. An array of 54 oxygen sensors were placed at 11 (ceiling), 9.5, 8, 6.5 and 5 foot elevations (see Figure 4-A-2), and 2 thermocouples were placed at 3 and 5 feet from the spill. The temperature profile is shown in Figure 4-A-3. The results were as follows:

1. The release of gas from a 50 K spill test class incident was first observed in less than 20 seconds by a PASS alarm in the Cryogenic Control Room and, second, as shown

by Figure 4-A-1, by annunciation of the process instrumentation in about 3.5 minutes as pressure degraded.

2. Helium did not entirely displace the atmosphere at any monitored location. The lowest O_2 concentration was 9% for ~3 minutes at the 6.5 foot level 20 feet from the spill, everywhere else the concentration was higher.
3. Without fans, observation via video tape and instrumentation showed that helium rapidly diffused and did not collect or pool anywhere. Note the attics that are covered with bars were not considered.
4. No “river of helium” was observed in this test.
5. Because the temperature at the thermocouple within about 36 inches of the spill did not go below -50° C (and only for a very brief time), there is no freeze hazard beyond that distance from the spill.
6. The oxygen concentration at the vertical escape hatch did not go below 19.5% oxygen. The concentration at the ceiling of the alcove adjacent to it reached 16%, but increased to above 19.5% in approximately 5 minutes.

There have been several other spill tests conducted to determine the effects of helium releases on oxygen concentration which are presented in the data shown in Appendix 5. In all these tests with liquid helium, the spills were accompanied by white vapor clouds, as well as being accompanied by very high noise levels. These effects provide warning that an event has occurred. As expected, these tests found the helium tended to rise as it propagated. As shown in Appendix 5, tests were performed during the ISABELLE/CBA Project using compressed helium in the Collider tunnel at flow rates from 1-15 g/sec. The ISABELLE/CBA tests did not result in oxygen concentrations lower than 20% by volume.

A question was raised concerning the potential for a very small and less catastrophic release to cause an ODH condition and to evaluate the concern that helium would pool and remain in high places, such as the Q5 Alcoves and the vertical escape hatches. These areas at the time of the test had no forced ventilation and were proposed as a special class of potential ODH hazard due to the possibility that it would be difficult to remove the pooled helium gas following a release. This test proved that the concern was unfounded since. The tests in the Collider tunnel were conducted at flow rates of 4-228 ft^3/hr, shown as BNL RHIC 1-4 in Table 4-A-3. The gas was released from a 1A cylinder at floor level. There was no change in oxygen concentration observed except directly at the hose outlet. Another test was conducted by opening the valve to a 1A cylinder of helium at floor level and discharging it upward into the Q5 Alcove. The Alcoves are unventilated raised cube shaped volumes adjacent to the multiplate arch tunnel ceiling. Again, no change in oxygen concentration was detected, even at the ceiling directly above the discharge.

Finally, the end of the discharge hose was placed at the ceiling of the Q5 Alcove. Over 600 cubic feet of helium was released at a rate of 228 ft^3/hr. This created an oxygen deficient atmosphere at the ceiling, which extended downward for a distance of two feet. After 17 hours, there was no oxygen deficient atmosphere in the Q5 Alcove. Note that this space is already covered with bars to prevent occupancy. This last test was not representative of a potential release, but demonstrated that helium will rise and partially displace air at the top of a volume and will diffuse to non-hazardous concentrations within a relatively short time. All test results are compared in Table 4-A-3. The time to ODH is based upon a tunnel volume of 294,000 ft^3 and, in accordance with the method in RHIC OPM 5.2.2.4.1, a helium release volume of 20,874 ft^3 is necessary to cause a reduced ambient oxygen concentration of 19.5% by volume throughout the tunnel.

The slow leak tests provided more empirical data on the mechanisms involved in a helium release. These data show that helium gas tends to diffuse in air rather than pool at very low flow rates. Higher "leak" velocities will increase mixing and diffusion. In addition the higher flow rates will be accompanied by significant visual and/or aural manifestations which will be readily and unmistakably detected by anyone within potentially hazardous range of the discharge point. If a significant and potentially hazardous helium discharge occurs, then the earliest detection will be provided by a detector sensor located at ceiling height. Once fans are activated, the ODH volume is expected to be limited to within a few feet of the leak point.

TABLE 4-A-3

Comparison of Helium ODH Tests

Test	Helium Source	ft^3/hr	Total Volume Released (SCF)	Time to ODH (hours)
BNL RHIC 1	Warm Gas	4.97	5	4200‡
BNL RHIC 2	Warm Gas	40.33	13.3	518‡
BNL RHIC 3	Warm Gas	137.328	45.8	152‡
BNL RHIC 4	Warm Gas	228.66	280	91‡
BNL 50 K Spill	Cryogen		21,000	<20 sec
BNL CBA 1	WarmGas	794.4	N/A	26
BNL CBA 2	Cryogen	3972	N/A	5
BNL CBA 3	Cryogen	7944	N/A	2.6
BNL CBA 4	Cryogen	11916	1192	7.15
CEBAF1	Cryogen	92500	1850	0.11
CEBAF2	Cryogen	200000	100000	0.1
FNAL	Cryogen	1050000	8750	0.02

‡Extrapolated
N/A = Not Available

From tests performed at BNL and other facilities, the following conclusions are drawn for the RHIC Complex:

1. Ample warning of a 50 K spill test class of release is given to a worker in the tunnel by:
    a. Pipe noise at 143/120 dBA, which was measured near the release.
    b. The white vapor cloud, which was dramatic but not hazardous, except within a few feet of the point of release.

2. The effect of 9% oxygen, the lowest observed, would be the inability to move, nausea, and vomiting, if the worker could not/did not move away from the area within ~4 minutes. Since the effected volume is small and localized, emergency egress is possible.
3. A release of helium that is slow enough to be silent poses no hazard and would ultimately be detected.
4. With PASS and fans available, helium would be easily and rapidly swept out.
5. Given the noise and visual effects, the PASS alarms are not a primary means of annunciation, and it is not credible that any worker will remain in the tunnel during a 50 K spill class release.
6. Pipe rushing noise is actually the best and most effective signal that a major helium release is in progress.
7. The PASS alarms are not needed to alert personnel that helium release has occurred.
8. The ODH monitoring system will be used to automatically start the emergency fans and will alert cryogenic operators that a leak has occurred.
9. Operator intervention would mitigate a real incident and limit the release.
10. All the escape routes and doors (vertical and horizontal) are safe without PASS and fans above 50 K and with PASS and fans below 50 K.

A.7. <u>Oxygen Deficiency Hazard (ODH) Monitors</u>

Function and Rationale: ODH Monitors show the oxygen concentration in a range (typically) of zero to 25% oxygen in air. In the Collider Tunnel, fixed monitors would provide an alarm if a sudden large release of helium were to occur. Moreover, with several sensors distributed along the axis of the enclosure it would be possible to deduce the rough size of a leak by the propagation time down the line of sensors and by the rate of decrease of the oxygen concentration at each location.

Placement: Response time for an ODH detector may be as long as 10 seconds, because it is a diffusion type fuel cell. The propagation speed of the helium front from a moderate sized leak, 15 g/s (195 SCFM), was empirically determined to be 1 ft/s during tests in the RHIC Collider Tunnel. The front speed was 0.6 ft/s for a 1 g/s leak. During the tests using release rates of 1 to 15 g/s in the

RHIC Collider Tunnel (see Appendix 5), the oxygen concentration never dropped below 20% at the detectors located along the ceiling of the tunnel. These earlier tests also showed that small leaks into the Collider Tunnel will not require immediate detection to prevent a hazardous condition for personnel and that helium propagates quickly in the horizontal plane and generally rises. Because of this tendency to rise, as helium is less dense than air, large releases will tend to accumulate at ceiling height. If a detector is placed at this height, it will provide sufficient warning that the breathing zone may go below 19.5% oxygen which is an insidious danger to personnel. The maximum spacing between detectors would be about 360 ft. With a 1 g/s leak, helium would take approximately 300 seconds to travel 200 ft to reach the detector and an additional 10 seconds for the detector to respond. Larger leaks would be detected more rapidly.

The following points were considered significant factors in the response to the ODH hazard in the Collider Tunnel and the design basis for mitigation:

1. Because helium is buoyant, exhaust fan ducts should be located in or as near as possible to the roof of the "attics."
2. Air supply fan inlet ducts should be located near the floor.
3. Fans should be provided with minimum capacities as shown in Table 4-A-4.
4. Anytime that personnel access is permitted in the tunnel and there is helium present below 50 K an emergency vent fan should be activated automatically whenever the oxygen concentration is detected below 18% at ceiling level.
5. In order to minimize condensation of water vapor from the air pulled in by the fans, only as many fans as are needed to ensure the safety of personnel in the Collider tunnel should be activated. If only one ODH sensor indicates a low oxygen concentration, only the fan nearest to that sensor should be activated. A logic diagram for the sequences of events following an ODH alarm is shown in Figure 4-A-4.

TABLE 4-A-4

RHIC Sextant 5 Emergency Air Flow

Location of Duct	Ceiling to Floor - Feet	Ceiling to Duct Top - Feet	Floor to Duct Bottom - Feet	Duct Dia. - Feet	Inlet Feature	Exhaust Fan Capacity - CFM	Comments
Approach to 4:00	14.0	5.4	4.6	4.0	Louver		Diffuse down
4:26 Hall	12.0	7.5	1.0	3.5	Louver		
4:26 Hall	12.0	7.5	1.0	3.5	Louver		
Opp. Alcove A	12.0	.5	7.5	4.0	Louver	20000	
Collider Tunnel	11.0	6.5	1.0	3.5	Louver		
Opp. Alcove B	18.5	.5	14.5	3.5	Louver	20000	
Collider Tunnel	11.0	6.5	1.0	3.5	Louver		
Opp. Alcove C	12.0	.5	7.5	4.0	Louver	20000	
Injection Area	14.0	4.8	5.2	4.0	Louver		Diffuse down
Injection Area	14.0	4.0	5.2	4.0	Louver		Diffuse down
Injection @ 6:00	14.0	5.0	5.0	4.0	Louver		Diffuse down
Injection @ 6:00	14.0	5.0	5.0	4.0	Louver		Diffuse down
Alcove A,B,C Exits	N.A.	N.A.	7.0	N.A.	Louver		Louvers open with any fan on

A.8. ODH Calculations

Systematic studies of the potential hazard which could arise from a cryogen release into each one of the buildings in which the Cryogenic System is housed have been completed. The most complex modeling problem occurs in the Collider tunnel. Figure 4-A-5, Relief/Vent/Release Design Path, depicts the considerations for this and other, closely related, subjects. The four major branches in the path reflect specific calculational problems which have been addressed. Table 3-Q-1 gives the Baseline Parameters for quantities of helium used in these release calculations.

The path furthest to the left, Branch 1, refers to calculations for pressure rise and relief during magnet quench events. Approximately 75 MJ[1] of energy is contained in the magnetic fields of one ring of magnets which are all connected in series. Almost all of this energy is extracted (4 to 11 second time constant) by the energy extraction system in the event that a magnet quenches. Although not considered likely, if beam or vacuum loss should quench all the magnets in one sextant each of these magnets would absorb its own energy with about 12.5 MJ being deposited into these magnets in a short period of time. Heat transfer rates limit the rate at which this energy is finally deposited into the helium. The maximum rate observed in tests[9] was about 6 kW per dipole. For a sextant this would result in a total rate of 192 kW. This rate may be compared to the estimated 320 kW[4] to 500 kW[11] seen by the same group of magnets during a vacuum failure with helium in the vacuum tank. The rate is smaller in magnitude and, because only a finite amount of energy is available, the duration is limited.

Branch 2 of Figure 4-A-5 represents, typically, a leak in a warm pipe which is connected to a vacuum jacketed cryogenic system. A line to a room temperature relief valve would be an example. If this type of leak were to occur, helium would be released into the room at a rate dependent on the hole size and the fluid conditions, i.e., pressure and temperature. If a leak in a sextant is large enough, ODH monitors will detect the accumulated helium, the exhaust fans will be turned on and the helium removed. Valves will then isolate the sextant. This type of leak has a natural limiting rate. That rate depends on the heat influx to the magnet (or any other) system and how much helium will be pushed out as it expands. Because the helium leak in this case is not into the vacuum space, the heat leak for the sextant will be unchanged at about 700 Watts. In an isentropic expansion from the

RHIC nominal operating conditions (4.5 K, 4.5 atm) 5.8% of the helium will be released as it is depressurized to one atmosphere. This release is about 10,000 SCF equivalent. A similar result, but with a somewhat higher release rate, would occur if the vacuum were to fail in a section of vacuum jacketed piping or in a valve box. In such a case, the heat leak would be relatively low and confined to areas removed from where the bulk of the helium is located.

The worst case, from the heat influx limit point of view, is clearly in the Magnet circuit where a common insulating vacuum space from magnet Q4 at one end of a sextant to magnet Q4 at the other end of the same sextant allows high rates of heat transfer to a substantial fraction of the helium contained in a sextant. For this reason our studies have focussed on this part of the system.

Branch 3 represents what could happen in the case of a vacuum failure caused by air leaking into the magnet insulating vacuum space in the Q4 to Q4 region. The measured heat transfer rate[5] under this circumstance is much less than the rate[6] when the vacuum is spoiled with helium. Because of the nature of the leak, no helium will be discharged into the tunnel so there is no ODH. In the worst case, some helium would be lost up the vent stack when relief valves opened to relieve the process pressure.

Branch 4 leads to the maximum helium discharge rate into the tunnel. This is the result of a catastrophic helium leak into the magnet insulating vacuum space. The calculations[11] for this type of release show that, for large assumed hole sizes, the discharge rate to the tunnel is ultimately limited by the heat transfer considerations in this geometry. This discharge rate, a profile with a peak of 150,000 SCFM equivalent (12,000 g/s) which occurs during the first few seconds of the event, is used to calculate[2] the ODH classifications in the Collider tunnel. This rate is based on the assumption that all of the cold helium contained in one sextant of the magnet loop is released into the vacuum tank instantaneously. The heat flux[11] into the vacuum tank is calculated as 500 kW. A plot [11] of the calculated discharge rate and the cumulative quantity of helium discharged is given in Figure 4-A-6. A hole of 3.2 cm^2 in the magnet loop containment envelope would be required, using sonic velocity at prevailing conditions, to reach this limiting rate of 12,000 g/s into the vacuum tank. The only mechanism seen which might have this potential is a short to ground from the magnet superconductor. The magnet circuits are checked to a potential of 5 kV before cooldown. This potential is the equivalent of 2.5 kV in helium at operating conditions where the highest voltage expected (during a quench) is 1.5 kV.

A similar calculation as that above was performed for an assumed leak into the 6 o'clock Valve Box. It was determined that helium would be released rapidly as the sextant was depressurized and then the flow rate decreased very rapidly. A plot similar to Figure 4-A-6 was generated and used to calculate the ODH class in the service buildings.

A summary of the results of the ODH calculations is shown in Table 4-A-2. This table also shows the building volumes and exhaust fan flow rates used in the calculations. The ODH Class for each location was calculated. Included in the statistical analysis is the probability of the failure of one of the exhaust fans in a set. The only area that is not ODH Class 0 is the Cryogenic Building (1005R) which is ODH Class 1. Although not currently proposed, this could be reduced from Class 1 to 0 if another fan of the same throughput (25,000 SCF) as one of the existing fans were installed.

A.9. Double Failure at Sextant 5

A study of Sextant 5 is presented here to illustrate some aspects of the ODH in the Collider tunnel. An elevation view for this area is shown in Figure 4-A-7. Sextant 5 is the only sextant which is connected directly to a heavily occupied building, 1005S. Labs occupy the ground floor and offices are on floors two through four. The small basement is a foyer for the stairway and elevator. A small equipment room for the elevator is located off of this foyer. The passageway (shown on Figure 3-F-1) from the Collider tunnel to the basement of 1005S has a cross section of 8 ft by 8 ft and the tunnel is isolated from 1005S by a fire door with automatic closers. A double failure mode was studied where the maximum release postulated above is accompanied by the simultaneous failure of all three exhaust fans. Such a failure is unlikely because the fans are on completely separate control circuits and are connected to the emergency power network.

Table 3-Q-1 shows at normal operating conditions the inventory of helium in a sextant is 663,500 SCF for both rings. However, the amount that can be released during an accident is the amount contained in the leaking helium circuit between the isolation valves. This quantity includes the helium in the equipment in the Collider tunnel and the connecting piping and the helium in the Valve Boxes. The isolation valves are located in the Valve Boxes at each end of each sextant. The

magnet circuit contains the largest amount of helium. This amount is equivalent to 175,000 SCF per sextant in the Magnet circuit as shown in Table 4-A-5. Five thousand SCF would remain in the vacuum tank, and the remaining 170,000 SCF would be discharged to the tunnel, if none is vented through some other means. If this quantity of helium were released following the maximum release profile calculated above and the ventilation system failed, it would require 1.5 minutes to fill the upper volume of the tunnel down to a height of 8 ft above the floor. At that time, the temperature of the helium and metal inside of the vacuum tank would be about 25 K. From that temperature upward the specific heat of the metal[8] increases rapidly with temperature and dominates the temperature rise so that the increase becomes progressively slower thereafter. It would require many hours for enough helium to be evolved to fill Sextant 5 from the ceiling down to the limiting height of 6.5 ft above the floor. Under these conditions, there is a potential for the helium to reach the fire doors in the basement of 1005S. The helium flow would be prevented or, at least, severely restricted by the fire door from the tunnel to the building and by another fire door into the stairwell in the basement. The elevator doors in the basement would also act as a barrier to helium seeking higher floors if it should enter the basement. No personnel are stationed in the basement of this building.

Assume another double failure mode, namely, that none of the isolation valves between the sextants close and the release sequence postulated above occurs. This would allow the helium volume from a whole ring to be vented through the leak. The flow rate would be increased by about 30% during the early part of the release until the pressure in all of the sextants has been reduced to nearly one atmosphere by the release of about 331,650 SCF from each sextant. If this increased flow rate were used to calculate the ODH classification it would remain unchanged at zero. After the initial surge of approximately 2 to 3 minutes in flow the other five sextants will contribute, by virtue of their low heat leak, only about 2000 SCFM additional flow to the flow from the sextant with the leak. The peak discharge rate into the Collider tunnel under these circumstances is 195,000 SCFM for a few seconds duration. The exhaust fan flow rate is 60,000 SCFM. This fan flow will prevent any significant accumulation of helium in the occupied part of the tunnel.

TABLE 4-A-5

Baseline Parameters for RHIC Helium Release Calculations

	Equivalent Volume (×1000 SCF)
TOTAL SYSTEM INVENTORY Ref. RHIC Design Manual	5485
HELIUM CONTAINED IN MAGNET COOLANT LOOP Ref. RHIC Design Manual, Table 3-10	
Total, both rings	3240
1 Sextant of 1 Ring	175
RING HELIUM CONTENTS BY LOCATION Ref. RHIC Design Manual, Table 3-10	
Magnets	3240
Piping	1374
Recoolers	206
Total - all sextants, both rings	4820
1 Sextant of 1 Ring	461

Neither of the two double failure modes which were studied indicate that the double failures are likely to cause a life threatening condition.

A.10. <u>Implementation of ODH and Access Controls</u>

During the cooldown of the Collider, the refrigerator has two cold process sources that are independently controlled and delivered to the accelerator - 55 K from Coldbox 3 and 4 K from Coldbox 5. As shown in this SAD, ODH detection and mitigation are a requirement at 4 K to maintain an ODH Class 0.

A quantitative determination was made of the temperature at which controls must be implemented to protect personnel. The lowest temperature at which the cryogenic system could operate before the PASS functionality and fans are mandatory for the protection of personnel with the ODH category remaining ODH Class 0 is 50 K. Above 50 K, due to the decrease in density, the release rate would be 10% of an accidental release during 4 K operation. The calculations (Appendix 46) showed that the Collider would remain ODH Class 0 without the fans or PASS in operation at temperatures above 50 K. Therefore, the Collider will be placed on Restricted Access and the ODH functions of PASS will be implemented for cooldown at 50 K.

B. RADIATION LEVELS ASSOCIATED WITH OPERATION OF THE RHIC TRANSFER LINE

The calculation of prompt radiation dose in regions exterior to the berm over the Transfer Line between the AGS and RHIC is shown in Appendix 17. The calculation assumes a beam intensity which is the equivalent of 2×10^{11} protons per bunch, and that 114 bunches are to be delivered to each collider ring. This is 4 times the design intensity shown in Table 1-A-1, which allows foreseeable intensity upgrades to be within the Safety Envelope. Appendix 17 also assumes that the neutron Quality Factor (a measure of biological radiation risk for a given energy deposition density in tissue) is 2 times the regulatory value. This assumption, which is also made in all subsequent calculations presented in this document, conforms with guidance for new facilities in the BNL RadCon Manual.[15] It is therefore important to note that, in the absence of future regulations regarding Quality Factor values, the best estimates of actual dose equivalent are half those presented throughout this document.

The source term for beam loss in the Transfer Line is specified in the Beam Loss Scenario in Appendix 8. As described there, normal beam loss in most regions of the Transfer Line is expected to be very small, nominally 0.05% of the beam injected into the Collider at a single point and 0.10% over the entire length of the Line. A beam stop is located in the Transfer Line where the X- and Y-Lines split from the W-Line,

where allowance is made in the Beam Loss Scenario for an annual disposal on this dump of two orders of magnitude more beam than is lost in the rest of the Line. Furthermore, the possibility exists that tail-scraping collimators, should one be located in the Line at a later date, may be a source of loss comparable to the dump. A summary of the results from Appendix 17 are shown below.

Dose Equivalent Rate

Big Bend Region: 0.26 mrem in an hour

Other Regions: 0.15 mrem in an hour

Annual Dose Equivalent

Big Bend Region: (mrem/yr)		Other Regions: (mrem/yr)	
Au:	276 mrem	Au:	162 mrem
Protons:	32 mrem	Protons:	18 mrem
Total:	308 mrem	Total:	180 mrem

The maximum loss over tens of seconds is of interest for determining the sensitivity of area monitors (e.g., Chipmunk) response. The least sensitive area would be "Other Regions":

Au: 1.43 mrem/hr

Protons: 3.12 mrem/hr

Fault Dose Equivalent Rate

Loss of the full proton beam on an arbitrary point, five times a year which persists for two AGS pulses (4.8×10^{12} 28 GeV protons):

Big Bend Region: 12.5/fault, 63 mrem/yr

Other Regions: 7.0/fault, 35 mrem/yr

An order of magnitude higher than normal loss for 5% of the fills on an arbitrary point:

Big Bend Region: 154 mrem/yr

Other Regions: 90 mrem/yr

Total Fault Dose Equivalent:

Big Bend Region: 217 mrem/yr

Other Regions: 125 mrem/yr

Skyshine (from normal injection operation and faults)

Collider Center: 0.0055 mrem/yr

Site Boundary: 0.0002 mrem/yr

Skyshine from Transfer Line Dump (set-up and studies)

Location	Distance (m)	Yearly Dose (mrem)
Thompson Road	14	3.8
Power Supply House	16	3.1
Collider Center	365	.012
Site Boundary	1060	.00045

C. RADIATION DOSE FROM THE COLLIDER BEAM STOP AND COLLIMATORS AND ASSOCIATED GROUNDWATER PROTECTION

Direct Radiation from the Beam Stops

The Collider Beam Stops, located on either side of the 10 o'clock intersection region will account for about 85% of the total loss of beam energy. The analysis of this loss is shown in Appendix 21. The upgrading of the earth shielding over them to 17.5 feet will limit the nearest offsite location on the east side of William Floyd Parkway to less than 1 mrem per year[83]. A small area of the berm over the Beam Stop regions will be fenced and controlled as a Radiation Area to exclude non-radiation workers.

Skyshine

Shortest Distance to William Floyd Parkway: 0.8 mrem/yr, lower in occupied areas.

Closest Onsite Uncontrolled Area (Building 1101): 2.5 mrem/yr.

Direct Radiation from Collimators

The primary beam collimators are located on either side of the 8 o'clock intersection region. It is assumed that 20% of the beam in each ring will interact on the collimator and, at most, 10% of the stored beam in one hour. The analysis of this loss is shown in Appendix 25.

Losses on the collimators for both normal and DBA conditions produce levels that exceed the criteria for a low occupancy uncontrolled area. To exclude occupancy, the zone will be fenced and an additional three feet of shielding will be added to reduce the offsite dose to the nearest point on William Floyd Parkway to less than 1 mrem/year. The dose to the nearest onsite high occupancy area, Building 1101, is 1.1 mrem/year.

Induced Activity in Soil and Groundwater

A very small amount of soil activation will occur in the sand around the Collider Beam Stops at 10 o'clock as a part of routine operation. The calculations for this section are shown in Appendix 47. The two principal isotopes, ^{3}H and ^{22}Na, will be induced in soil within 40 cm of the tunnel wall and floor in concentrations in soil of 2.2×10^{5} and 2.8×10^{5} pCi/liter/yr, respectively. It should be noted that there are no potable water sources near the Collider Beam Stops.

It is the goal of the RHIC Project and the Laboratory to achieve as close to zero environmental impact as possible. To minimize the leaching of induced radioactivity from the soil that surrounds the Collider Beam Stops and collimators, an "umbrella" in the form of a waterproof membrane will be placed over the affected areas before the existing berm is upgraded to the required 17.5 and 16 feet of shielding, respectively. Upgrading the berm in the vicinity of the collimators will be completed at the time the collimators are installed. The "umbrella" will effectively trap the vast majority of induced radioactivity, causing it to accumulate above the water table. This will result in much lower concentrations of radioactivity in the groundwater than those stated above.

If no umbrella was installed, a conservative prediction of the possible concentration of tritium and sodium-22 can be made by assuming that approximately half of the total amount of annual precipitation (55 cm of the total of 122 cm annual average) leaches through the most activated of these soils, and the remainder of the precipitation is lost due to evaporation or evapotranspiration. Under this scenario, the annual average tritium and sodium-22 concentrations in soil pore water directly below the beam dump areas may be as high as 1.7×10^5 and 2×10^4 pCi/l, respectively. However, the annual volume of water with these concentrations would likely be less than 40 gallons at each beam stop, and there would be significant dilution of this water within a short distance upon entering the aquifer system.

By preventing rainwater infiltration, the tritium and sodium-22 pore water concentrations are predicted to be reduced by a factor of at least 100, to concentrations in the range of 1,700 pCi/l and 200 pCi/l, or 8.5% and 49% of the New York State Drinking Water Standard, respectively. The concentration in the collimator areas at 8 o'clock are approximately five times less than the Beam Stop potential.

From the Beam Loss Scenario (Appendix 8), the total annual energy on the W-Line Beam Stop is equivalent to 1.53×10^{14} Au ions per year at 10.4 GeV/u. This is 2.7% of the energy on either of the two Collider Beam Stops. If one compares the maximum star density in soil per year at the W-Line Beam Stop to either of the Collider Beam Stops, it is 4.5% in the forward direction and 0.08% in the transverse direction. The 4.5% would give 7650 pCi of ^{3}H per liter at the water table in the same model used for the Collider Beam Stop (Appendix 47). Furthermore, the volume of soil is only about 10 liters in this geometry. Therefore, mitigation at the W-Line Beam Stop was not deemed necessary.

To verify that the operations of RHIC do not impact groundwater or surface water quality, the BNL routine groundwater monitoring program was augmented in the vicinity of the Beam Stop and Collimators with additional monitoring wells, and routine surface water sampling downstream of the Peconic River culvert. The monitoring program shall begin at least one year before the start of Routine Operation of the Collider. The monitoring plan and assessment of groundwater impacts is shown in Appendix 21.

Internal Residual Levels from Beam Stops[84]

Induced Activity Near the Beam Stop from Appendix 23:

Cooling Time	1 ft from Marble	1 ft from Exposed Core
1 hr	16 mrem/hr	608 mrem/hr
1 day	5 mrem/hr	150 mrem/hr

D. COOLING WATER ACTIVATION AND RADIATION DOSE FROM AIR ACTIVATION

Cooling Water Activation

Calculations were performed to assess ^{3}H production in cooling water used by the experimental systems. Because the source of beam loss is due mainly from beam-beam interaction, the water is exposed to small flux of secondary particles. The methodology is shown in Appendix 40, and the results are summarized in Table 4-D-1.

TABLE 4-D-1

Estimated ^{3}H Activity Concentrations

System	pCi/l for 1 Year Running at Design Luminosity	Comment
STAR Magnet	<0.23	Main Coils Only
STAR SVT	4.1	
STAR TPC	0.20	
STAR Electronics	<.09	Closest Point Only
PHENIX Magnet	0.18	
PHENIX MVD***	2.2	(Capacity 4.1 Gallons)
BRAHMS Magnet	<0.40	η = 0 at All Points
PHOBOS Magnet	1.1	
PHOBOS Silicon	21.8	

***Not actually water: FC-25 treated as if it were water.

Air Activation

The calculations and results shown in Appendix 20 and Appendix 9 were scaled to reflect the Beam Loss Scenario in Appendix 8. This increased the results by approximately a factor of two. Air activation would produce 0.03 mrem/yr at the site boundary, if somehow all the activity were released 250 meters from it. In reality, activated air is released only by natural circulation causing almost all of the very short-lived activity to decay in place. Therefore, the actual site boundary will be a small fraction of 0.03 mrem.

E. RADIATION DOSE FROM MUONS

A detailed calculation of the dose impact from muons was provided in the Preliminary Safety Analysis Report. This calculation was updated based on the Beam Loss Scenario, the actual locations of the Limiting Aperture Collimator and the Collider Beam Stop. The initial analysis and update to it are in Appendix 19.

The site boundary muon dose from the Beam Stop at 10 o'clock and collimator at 12 o'clock is estimated to be 0.15 to 0.42 mrem/yr and 0.07 to 0.36 mrem/yr, respectively. Muon dose from the intersection regions is 0.035 mrem.

F. RADIATION DOSE FROM A DBA COLLIDER FAULT

The Beam Loss Scenario in Appendix 8 assumes that an uncontrolled loss of a beam at full energy is possible at a location other than at the intended loss point, the Beam Stop at 10 o'clock. In the case of a DBA Collider fault with a 4 times day-one intensity proton beam, it is assumed that, for most locations in each ring, half the beam (the equivalent of 1.14×10^{13} 250 GeV protons) is lost at a point and the other half distributed over an extended length of magnets. The entire beam could be lost at an aperture-defining location including the high ß quadruples. At the superconducting Tevetron at Fermi National Laboratory the entire full energy beam has been lost twice in approximately 10 years of running to date, but in both cases the loss was distributed over a long portion of the machine. The maximum credible loss defined here is therefore conservative. The maximum dose, using the method shown in Appendix 15, from a DBA fault to an individual standing at a typical location on the berm is currently estimated to be 114 mrem. This dose is less than the RHIC Design Criteria of 160 mrem/fault. Note that if the actual legal neutron Quality Factor is applied, the DBA fault dose estimate on the top of the berm is 57 mrem. However, a more stringent administrative limit has been established.

The policy of RHIC Project Management is to increase beam intensity slowly, so that uncertainties in estimates of the dose potential can be resolved by a series of fault studies. During Commissioning and the first year of operation, for example, the intensity will not exceed ½ of design

(Appendix 34). The intensity will be limited so that the dose in the case of full beam loss at full energy at a typical point on the top of the berm in an Uncontrolled Area will not exceed 34 mrem.

G. RADIATION DOSE THROUGH MULTI-LEG AND STRAIGHT-THROUGH PENETRATIONS

All the multi-leg penetrations in the Collider, U-, W-, X- and Y-Lines were analyzed with the methodologies by Gollon and recalculations by Stevens are both described in Appendix 16. The results in Appendix 16 were amended to clarify them to the as-built drawings.[84] One exception is the entrance to the U-Line at UGE1 (FEB Gate-1) at the U-upstream end of the U-Line. That penetration is dominated by a g-2 source term and is reported in AGS Safety documentation.

The results for the Collider ventilation shafts are shown in Table 4-G-1. The values reported in the Table are shown for the dose equivalent at the beam surface and for the vent fan cover at three feet above the berm. Many of the vent fans extend higher than three feet but, for the purpose of access control, no additional credit will be taken. The labyrinths in the Transfer Line were analyzed assuming a fault with an AGS injection loss (4.8×10^{12} 28 GeV protons), and the Collider labyrinths used a DBA fault (1.14×10^{13} 250 GeV protons). Those archetypes that exceed the Design Criteria will be appropriately controlled to exclude occupancy on top of the shaft cover.

The results for the access and emergency egress labyrinths and escape hatches are shown in Table 4-G-2. There is an interlocking Chipmunk at the exit of the curved labyrinth, WGE2 at the X-Y split. Fault studies were conducted at most of the penetrations in the Transfer Line during the 1995 commissioning run. They were found to be within the predictions.

There are a number of straight-through penetrations into the beam enclosures. They are cylindrical shafts used for survey and, large rectangular shafts on either side of the 6, 8 10 and 12 o'clock halls to permit cryogenic piping to bypass the experiments. The method used to assess these voids in the shielding is shown in Appendix 19. The doses directly above these penetrations for a DBA Collider fault are:

TABLE 4-G-1

Emergency Ventilation Ducts

Case	Archetype Description	Comment	Dia.	Distance to Beam Pipe	Vertical Source		Figure	Dose at Exit of Berm	At the Fan Cover
			(in)	(ft)	Length (ft)	Angle (deg)		(mrem/fault)	
A	Sextant 3 Concrete Structure at Spect. Tunnel		42	9.5	25.0	0	4-G-1	46	27
B-1	16 ft Plate Arch		42	7.0	15.5	0	4-G-2	486	270
B-2	16 ft Plate Arch		48	7.0	15.5	0	4-G-2	831	475
C	20 ft Plate Arch		48	8.5	16.5	0	4-G-3	507	298
D-1	26 ft Plate Arch		42	8.5	18.0	0	4-G-4	215	119
D-2	26 ft Plate Arch		48	11.5	18.0	0	4-G-4	238	136
E	Concrete Structure at 4 o'clock		48	8.0	16.5	0	4-G-5	555	326
F-1	Injection-Ejection at Sextant 5, 7	Near Wall	48	10.0	16.5	0	4-G-6	396	192
F-2	Injection-Ejection at Sextant 5, 7	Far Wall	48	14.3	16.5	0	4-G-6	224	132
G-1	Injection/Ejection at Wide Angle Hall	Near Wall	48	8.3	16.5	0	4-G-7	529	311
G-2	Injection/Ejection at Wide Angle Hall	Far Wall	48	10.0	16.5	0	4-G-7	396	233
H	RF Cavity Sextant 5		42	10.0	17.5	0	4-G-8	186	103
I-1	Alcove A and C - Typical		42	15.5	10.0	15	4-G-9	516	258
I-2	Alcove A and C - Typical		48	15.5	10.0	15	4-G-9	801	411
J-1	Alcove B - Typical		42	16.0	13.0	50	4-G-10	81	42
J-2	Alcove B - Typical		48	16.0	13.0	50	4-G-10	150	83
V-2	X-Y Arcs		36	6.7	16.0	0		55*	N/A
V-3	New Block Wall in W-Line		36	3.5	11.0	0		166*	N/A

*AGS Class Fault

TABLE 4-G-2

Access and Emergency Egress Labyrinths

Location of Archetype	Case	Drawing	Dose
			(mrem/fault)
Injection Line Exit at AGS to RHIC Transition	P-1	S-13/42	1*
Injection Line X-Y Split	P-2	S-13/42	32.3*
Alcove B	P-3	A-5/51	7
Alcove A and C	P-4	A-4/51 and A-5/52	70
7-B Emergency Exit (Typical)	P-5	A-5/51	33
Narrow Angle Hall to Support Building	P-6	A-3/8	19
4 O'clock Support Building	P-7	A-2/7	16
Ring to Building 1005S	P-8	S-1/56	13
Injection/Ejection Structure to Building 1007 and Emergence Above Ground	P-9	A-3/5 and S-9/38	3.6, 36
10 O'clock Tunnel Exit Through the Berm	P-10	A-3	2
Ring to 10 O'clock Support Building	P-11	A-3	270
12 O'clock Tunnel Exit Through the Berm	P-12	A-12	3
Ring to 12 O'clock Support Building	P-14	A-3A	11
8 O'clock Support Building	P-15	A-4/9	21
U-Line Near Fork to Old Neutrino Line	P-16	D14-1192 A6 Rev A-1	8*
6 O'clock Support Building	P-17	A-3/15	24
Escape Shaft Near Building 1005S (Typical)	P-19		60

*AGS Class Fault

Large Rectangular Cryogenic Piping Shaft - 12,000 mrem

12 inch diameter Cylindrical Shaft - 220 mrem*

18 inch diameter Cylindrical Shaft - 600 mrem

*For a DBA in the Transfer Line, with an injection beam from the AGS in accordance with the Beam Loss Scenario in Appendix 8, a dose of 15 mrem would result.

If a person were standing beside the cylindrical shafts in the Collider instead of directly above, the dose would be at least a factor of 10 less. To exclude personnel from the vicinity of the cryogenic piping shafts they will be secured by a 6 foot fence and locked gates under the control of the Heath Physics Watch. The area will be swept via procedure before operation with beam. The technical basis for the fencing around the cryogenic piping is shown in Appendix 19.

H. TRACKING OF SHIELDING AND ACCESS CONTROL REQUIREMENTS

Not every result of every shielding calculation is reported explicitly in the SAD or the Appendices. Many analyses are documented primarily in the minutes of the Radiation Safety Committee. There are a few radiation issues that must be tracked, as the machine intensity increases up to four times the Design Intensity. For example, portions of the access controls for the complex are not configured to protect against four times Design Intensity. Some of the fencing and barriers on "day one" may be only for initial running at low intensity or less than full energy beam. To track future needed calculations, the design and implementation of additional shielding, access control barriers, and commitments to construct approved shielding upgrades that are deferred until high intensity running occurs, a computer database was created. Appendix 27 shows a sample report from it. The items listed in the report are ordered geographically by location around the Collider. The "ID" number is simply a database identifier for a specific item. In the report shown, the appearance of consecutive entries with the same ID indicates "events" in the history of some item. The column labeled RSC indicates whether an official Radiation Safety Committee checklist number is associated with the recorded event. The last column indicates whether the entire history of events associated with an item is regarded as closed.

As examples of entries in the database, consider the items with ID numbers 36 and 46 at the 4 o'clock location. Item 36 refers to calculations of dose equivalent exterior to the shield at 4 o'clock based on the shield design on March 2, 1998. The second entry in the history of this item was the completion and review of the calculations, which closed item ID 36, but resulted in the new item 46. At the time of this writing, posting and additional fence is required in the 4 o'clock area and this item cannot be closed until this physical configuration actually exists.

Note that the items tracked in this database are in a continuous state of evolution, so that the report shown in Appendix 27 is only a snapshot in time. Many "issues" must be resolved for commissioning, but others only as RHIC approaches the Safety Envelope of four times the Design Intensity, so that closure of some items (e.g., item ID 51 at 12 o'clock) is not scheduled until well after RHIC operation has begun. On the other hand, as RHIC evolves (e.g., the addition of experiments) and as experience in running is accumulated, new issues will undoubtedly emerge. As new "issues" emerge the database will be updated but not Appendix 27.

In general, all open safety issues that require resolution before operation shall be tracked by the associated Operational Readiness Review.

I. RADIATION POTENTIAL FROM RF CAVITIES

The RF cavities located in the vicinity of the 4 o'clock region produce x-rays as a result of normal operation due to conditioning and multipacktoring. At full power, dose rates based on measurements during engineering tests of the Proof of Principal (PoP) acceleration cavity and Storage cavity are expected to be in the range of 25-200 rad/hr at 1 foot from the cavity (see Appendix 24). The power supplies for the cavities are interlocked to the PASS system, with the capability of stand-alone running when the Collider is not in operation. Sectionalizing gates inside the Collider Tunnel prohibit access to the cavities by personnel, when the adjacent tunnel is in an access permitted state to secure the cavity area for operation. Operation of the RF cavities will not cause levels of x-ray radiation outside the Collider shielding.

J. FIRE PROTECTION AND LIFE SAFETY

J.1. Description

General

Site Fire Alarm System: Brookhaven National Laboratory provides central alarm station coverage by an Underwriter Laboratory listed multiplexed Site Fire Alarm System. The system complies with the requirements of NFPA 72 for a Style 7D system. The system uses the existing site telephone cable plant. Each fire alarm panel has two channels on one of 7 communication loops for communication to the central system. The system can monitor more than 20,000 points. It is currently monitoring 3,800. Response time from alarm at the panel to alarm indication at the Central Station is less than 10 seconds, which is well within the 90 seconds allowed by NFPA. The main console is at the Firehouse, Building 599. This station monitors all fire alarm signals, trouble and communication status alarms. A satellite station is provided at Security, Building 50 for fire alarm signals only. If the Firehouse does not acknowledge an alarm within 90 seconds, the satellite station at Building 50 will receive an audible indication to handle the alarm. In addition to annunciation in the Fire House, alarms for RHIC will also occur in the Main Control Room.

Site Water System: BNL has a combination domestic and fire protection water supply system. The system is supplied by several deep wells and is stabilized by two elevated water storage tanks (one 1 million gallon and 350,000 gallon capacity). The wells have electric primary drivers and a limited number have backup internal combustion drivers. The system can sustain three days of domestic supply and a maximum fire demand for BNL with two of the system's largest pumps out and one storage tank unavailable. The grid of the piping network allows great flexibility in water distribution. The RHIC Complex is on the north side of the site. Two feeds from the main distribution system enter Ring Road, one at 5 o'clock and one at 6 o'clock. The water supply feeds can be isolated from each other by sectional valves. The distribution system on Ring Road is looped with isolation valves between facilities. Valves are present to isolate each fire protection feed at each sextant around Ring Road. Fire hydrants are provided within 300 ft of each facility.

Fire Department: The BNL Fire/Rescue Group is a full time, paid Department. Minimum staffing is six fire fighters and one officer. The fire fighters are trained to Fire fighter Level III by International Fire Service Training Association, National Fire Protection Association (NFPA) Fire Fighter Level II, and NFPA Hazardous Material Technician Level. They also provided emergency medical services, with a minimum of two members per shift holding New York State "Emergency Medical Technician D" certifications. The Group operates a Basic Life Support ambulance. Additionally the Group has two 1500 gal/min pumpers, one heavy rescue vehicle, one Command Post

Vehicle and one brush truck. The single Fire Station is on the west side of the site. Response time to the most remote section of the RHIC Ring is less than eight minutes.

Transfer Line, AGS U-Line

The AGS U-Line (Building 927) is a non-combustible corrugated metal structure, with a Class A Flame Spread Rating, as per ASTM E-84. It is an underground, windowless structure, covered by a several feet of earthen berm. No exterior fire exposure exists. The specific safety documentation for the AGS Complex is shown in the AGS Safety Analysis Report.[64]

The entire U-Line is fully sprinklered by a dry pipe sprinkler station in Building 927. The exception is a sealed chamber to the north of Building 927. The chamber has no contents nor access. There is no fire detection system in this section of the U-Line tunnel, only manual fire alarm stations at the exits.

The upstream W-Line branches off from the U-Line and ends up at the headwall that separates the upstream and downstream W-Lines. The only penetration through the headwall is the beam pipe and a personnel labyrinth around it. While the wall is not a listed fire rated assembly, it is an adequate separation to exclude fire transmittal. A key factor is the low fire loading on both sides of the barrier. These fire loads are inherent with this class of accelerators and are not expected to increase.

The tunnel is occupied by conventional warm magnets, associated systems and cable trays. Full replacements and/or parts are available for the magnets. Cables used by former operations of the U-Line have been removed and replaced with IEEE 383 qualified cables and are not considered a major combustible. There are several RG-58 and RG-59 cables that are not IEEE qualified. These are UL listed as CL2. They do not pose an excessive hazard in a fully sprinklered facility. No other significant combustibles exist beyond the cables. Power supplies for this section of transfer line are housed in the A Power Supply House described below. Beam line instrumentation electronics is present in a trailer located to the east side of the U-Line.

Transfer Line, W, X and Y-Lines

This portion of the facility starts at the RHIC/AGS interface point (the headwall mentioned above), the downstream W-line, and the south portion of Building 1000A. The tunnel segment is called the RHIC portion of the Transfer Line. This section of the Transfer Line (Buildings 1000A, 1000E and 1000W) is a 12 ft diameter corrugated metal tunnel with a level walking surface. There is a wider transition structure by Building 1000A that is of concrete construction and does not pose any addition concerns. Several feet of an earthen berm covers the tunnel for radiation shielding. This cover precludes any external fire exposure problems effecting the tunnel operations. The interior surface to the tunnel is either bare metal or painted concrete, both have a Class A flame spread as per ASTM E-84. The fire alarm and protection systems are identical to the Collider Tunnel, which is described in the next section. The W, X and Y beamlines in this area are a conventional warm magnet system with cable trays. The cabling in the trays is IEEE 383 rated. Replacement magnets are readily available. The Switcher Magnet is the only exception. However, Switcher Magnet replacement coils are in critical parts stock. This would allow a fire damaged Switcher Magnet to be rebuilt within 1 month.

Collider Tunnel

The configuration of each sextant of the Collider Tunnel is similar. Each sextant is 32,150 ft.^{2} All of these structures were constructed in 1981.

The original designs of the Collider Tunnel for the RHIC project were done for the former ISA and CBA Projects. Under those construction projects, the Collider Tunnel was constructed with the intention of not installing full sprinkler protection. This required a deviation from the 1985 version of the National Fire Protection Association's Life Safety Code, which is DOE mandated.

The initial ISABELLE/CBA approach was to comply with the Life Safety Code in effect at the time of design, as required by DOE. During the progression of the project, the Life Safety Code changed. Formerly, the Collider Tunnel's configuration would require complete sprinkler protection. With the completion of four recommendations, the 1991 Code allows the existing configuration without full sprinkler coverage (local sprinkler protection may be provided for non-life safety issues).

The cost of sprinkler protection was originally estimated at less than $100k for full coverage. It has since been redefined at a cost in excess of $250k. DOE criteria (i.e., life safety, property protection, programmatic protection or environmental issues) with regard to the Collider Tunnel does not require the sprinklers to be installed. This represents a change from the commitment in the PSAR for RHIC.

Fire detection within the tunnel complies with NFPA 72 for a Style 7D system. Manual fire alarm boxes are provided by all exit doors from the tunnel and at midpoints between exits. Fire detection is provided on 40 ft maximum spacing in the tunnel. The narrow width of the tunnel places the effective area per detector at less than 500 $ft.^2$ Each detector location has a spot type smoke detector and a separate heat detector. Separate zones are used for the heat detectors/fire manuals and smoke detectors. The smoke detectors alternate between photoelectric and ionization type of detectors, as a best management practice. Photoelectric detectors detect smokey electrical fires better, while ionization detectors are more sensitive to clean burning, ordinary combustibles. Since history with accelerator tunnels has shown that there will be occasions when smoke detectors need to be deactivated (cutting/welding in the area, internal combustion vehicles, system troubles, grinding operations), the dual system of smoke detectors and heat detectors has been installed to permit deactivation of the smoke detectors for special types of maintenance while maintaining a minimum level of fire detection. The heat detector zone, and the associated manual fire alarms on that zone, would remain in service, allowing continued facility operations. Fire alarm bells and strobes have been provided in the tunnel to provide notification to the facility occupants. This complies with NFPA 72H and ADA requirements.

The signals from the fire alarm system reports to the BNL Fire/Rescue Group through the Site Fire Alarm System as previously described.

In lieu of locating fire extinguishers around the ring to meet NFPA 10 for the normally nonoccupied tunnel, fire extinguishers are carried in with work carts during maintenance activities. This option avoids the problems associated with access maintenance of the extinguisher in radiological and ODH controlled areas and eliminates the need to monitor for activated extinguishers.

Since access into the tunnel is difficult for manual fire fighting efforts, standpipes have been provided in the Collider and Experimental areas. The four inch standpipe lines have 2 ½ inch connections reduced to 1 ½ inch outlets. Outlets are spaced every 150 ft. The standpipe is supplied by stations at 1002, 1004, 1006, 1008, 1010 and 1012. Fire department connections are located by the sprinkler/standpipe riser supply stations and at all B-Alcove exit points around the ring.

Because the Collider and Experimental Halls are windowless structures, a vent system has been installed to remove smoke. The exhaust system is designed to have a 100 ft/min. face velocity across the tunnel diameter in order to provide an air change every six minutes. Intakes and exhausts are at the exits and midpoints around the tunnel. The exhaust systems controls are divided by sextant. Manual activation of the emergency exhaust system is possible at the horizontal entrances. Fan activation will also be controlled by the Personnel Safety System. Fan activation is divided into sextants, corresponding with the fire alarm zones for the areas.

The descriptions and analysis of exiting arrangements and compliance with the NFPA Life Safety Code are found in Appendix 10 for the Magnet Enclosure Life Safety Analysis. Life Safety Analysis for Buildings 1002A, 1004A, 1006A, 1008A, and 1010, 1012, have been performed for this SAD since these structures provide "horizontal exits" for certain portions of the Magnet Enclosure.[65,66,67,68,70,71] One item has changed in the Collider Tunnel Life Safety Analysis. "Spur" tunnels have been added to the clockwise and counterclockwise sections of Buildings 1008 and 1012. These tunnels were added to provide additional access points to move magnets into and out of the Ring. They will be capped with shielding blocks at the exterior end. There will be locked and interlocked gates near the Collider Tunnel. The shield blocks and security will ensure that dead end distances are not exceeded for Occupied Areas.

The Life Safety Code Analysis in Appendix 10 includes four recommendations. They were resolved as follows:

a. Mid-sextant doors were removed, since they will be held closed against the airflow when the emergency fans activate. Removal of the doors does not result in the travel distance requirements being exceeded.

b. Doors from support structures were upgraded to 1 ½ hour rated.

c. Unless the tunnel is placed on an access permitted state, it is not desirable for the emergency ventilation system to automatically start on an ODH alarm due to the risk of equipment damage from condensation. Emergency start switches have been provided at the access points for use by Fire/Rescue personnel to ventilate the tunnel as needed.

d. The entire emergency generator system was installed and is in service.

Equipment Alcoves

A detailed Fire Hazard Analysis is shown in Appendix 11 for the eighteen Equipment Alcoves located around the Collider. The following is a brief summary. Three Equipment Alcoves are located in each Sextant of the Ring. They are equally spaced along the Ring. The equipment alcoves are small rooms (15×17×12 ft high). These structures are also underground, and do not have external fire exposure potentials. Three Alcoves are in each sextant and are equally spaced. Six inch concrete block walls separate the alcoves from the Collider Tunnel. The doors between the alcoves and the Collider Tunnel were removed at the request of the Cryogenic Safety Committee. The Code does not require these doors to be in place. They were previously installed as a best management practice. Cable trays penetrate this wall, but are sealed with fire rated stopping.

The Alcoves are used for power supplies, beam line instrumentation, machine controls and vacuum system controls. There are no significant quantities of combustible materials or oils. All of the electrical installations comply with the National Electrical Code (NFPA 70). The cable used is all IEEE 383 rated.

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code are found in Appendix 10. The Life Safety Analysis for Buildings 1002A, 1004A, 1006A, 1008A, 1010A, and 1012A have been included since egress from the tunnel "horizontal exits" includes these structures.[65,66,67,68,70,71]

The alcoves are protected by spot type smoke detection. Manual pull alarms are also provided at entrance and exit doorways. Bells and Strobes provide local annunciation.

Support Buildings

Building 1000P: Building 1000P is a one story prefabricated insulated metal skin building of 2,400 ft^2. The facility is used for housing power supplies, vacuum systems, and beam line control instrumentation in support of the Transfer Line. The power supplies represent the largest dollar value in the building. There are four large SCR power supplies, valued at $100k each. They are not oil filled and have small combustible content (coil windings, printed circuit boards). There is an additional eight 10kW to 20kW power supplies, valued at $10k to $15k each. Total value within the facility is approximately $600k.

The facility is provided with smoke detection, manual fire alarm pull boxes and local bells. To the west of Building 1000P is a transformer yard. A fire wall has been constructed to isolate the transformers and protect the building as per Factory Mutual Data Sheets. There are no other fire exposures to this facility. Emergency power is provided by generator for lighting.

The descriptions, analysis, exiting arrangement and compliance with the NFPA Life Safety Code of Building 1000P were conducted as part of the overall RHIC life safety survey.[71]

Buildings 1005S and 1005R: Building 1005S is a four story insulated metal building with a basement, built in 1981. The floor/ceiling units are poured concrete on a metal deck. Two-hour, sprayed on, fire resistive coating has been applied. Interior stairwells are two-hour fire rated. One vertical shaft connects the third floor (RHIC Control Room) to the basement access to the Collider Tunnel. The original use of this shaft was for control cabling for the RHIC Accelerator. With the uses of fibre optics and the RHIC control architecture, the shaft is virtually empty. Plans are to protect the shaft with fire rated enclosures once the control room is fully configured. The roof is a Class I steel deck roof per Factory Mutual Standards.

The main facility is used for offices on the second, third and fourth floor. A portion of the third floor houses the RHIC Control Room and has a separate one-hour fire rated enclosure. No underfloor fire detection or mitigation system is necessary, because the bulk of the wiring placed under this floor will be fiber optics or other data buss type signals (low power, low case flammability) which can be rapidly replaced and at low cost while an alternate Control Room is established by utilizing another parallel node on the network.   The west section of the first floor is used for technician labs (table top electronics work, no flammable liquids). The shops are separated from the office spaces by a two-hour fire wall and two-hour sprayed on fire proofing on the ceiling.

Appended to Building 1005S is a highbay with a Class I steel deck roof on the east side. The lower level of the highbay contains a tech shop and a test stand for development of RF cavities. A two-hour fire rated wall separates it from the multistory section. It is approximately 3,000 ft^2 of the total 45,700 ft^2 for the facility. It is a low fire hazard occupancy by NFPA 13 Standards.

Adjacent to Building 1005S on the west side is Building 1005R which contains the refrigerator portion of the cryogenic plant. This is a one story building of approximately 7,000 ft^2 It is built on concrete slab, with concrete block walls and a Class I steel deck roof per Factory Mutual Standards. Portions of this structure have an external insulation system of polystyrene boards covered with a cementious covering. This arrangement complies with the guidance of Factory Mutual Engineering Association 1-57, Ridged Plastics in Building Construction. It does not pose an interior fire hazard. Vacuum pump oil is the main combustible material. This oil is normally contained in the pumps or stored in 5 gallon metal cans (DOT Shipping containers). This area also has an ODH monitoring system that is connected into the RHIC Personal Safety System and not into the Site Fire Alarm System.

All areas of Building 1005S have sprinkler protection. Building 1005R is fully sprinklered, except the area under the 3,600 ft^2 mezzanine and a 600 ft^2 prefabricated modular office. The area under the mezzanine contains compressors, in which the main hazard is lubricating oil. This high flashpoint oil is not pressurized and is contained within a steel housing. Sprinkler protection under the open mezzanine is not warranted. The modular office will have either sprinkler protection or it will be removed depending on operational requirements.

Standpipes are provided in the stairwells of this four story structure. The fire alarm control panel is connected to the on-site Fire/Rescue Group. Manual fire alarm pull stations are provided at each entrance to the stairways and at building exits. Bells are provided throughout to alert building occupants. The fire alarm system is connected to the Fire/Rescue Group via the Site Fire Alarm System. Fire extinguishers are provided throughout the facility to meet NFPA 10.

Building 1005S is sufficiently remote from other structures as not to have exterior fire exposure concerns from other facilities. However, the electrical substation supplying this facility is an exposure concern. The insulated metal panel on the multistory portion of the facility is insufficient to protect against a fire exposure. Corrective measures were completed as part of a Line Item Project addressing electrical substation loss prevention at BNL (Job Number 7969, LNI LPU95).

The descriptions, analysis, exiting arrangement and compliance with the NFPA Life Safety Code of Building 1005S and Building 1005R were performed as part of the overall RHIC life safety survey.[72,73]

Building 1005H: Building 1005H is a one story, concrete block walled building of 11,100 ft^2, built in 1981. The roof system is a Class I steel deck roof. Portions of this structure have an external insulation system of polystyrene boards covered with a cementious covering. This arrangement complies with the guidance of Factory Mutual Engineering Association 1-57, Rigid Plastics in Building Construction. It does not pose an interior fire hazard.

The facility contains the helium compressors for the RHIC cryogenic system. The occupancy is characterized as a mechanical equipment space with limited combustibles. The oil flooded rotary screw compressors contain 4,400 gallons of a high flash point oil (F.P. 450^{o}F). These are contained in a metal sump. The building automatic sprinkler protection is considered adequate for this hazard. Automatic sprinkler protection is provided throughout Building 1005H, except for the electrical distribution room which only has detection. Smoke detection, the water flow switch and the sprinkler post indicator valve tamper switch, are connected to the Site Fire Alarm System.

Manual fire alarm pull stations are provided at each entrance to the stairways and at building exits. Smoke detection is provided in the electrical switch gear room. Bells equipped with strobe lights are provided throughout to alert building occupants. The fire alarm system is connected to the Fire/Rescue Group via the Site Fire Alarm System. Fire extinguishers are provided throughout the facility to meet NFPA 10.

Building 1005H is sufficiently remote from other structures as not to have exterior fire exposure concerns. However, the electrical substation supplying this facility is an exposure concern. The interior of the facility is protected from potential damage by the concrete block wall with a generic fire resistance rating exceeding two hours. The polystyrene covering on the masonry wall will be damaged, but will not significantly contribute to the damage. The slope of the terrain and rock cover does preclude flowing burning oil damaging the structure. However, a basin is required for environmental protection. This was addressed by a Line Item Funded Project (Job Number 7969, LNI LPU95).

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code of Building 1005H were performed as part of the overall RHIC life safety survey.[74]

Building 1005H Cooling Towers and Pump House: The remote 30 ft by 40 ft pump house for the cooling towers on the west side of Building 1005H is provided with detection and enclosed in a one-hour fire rated room. The walls are masonry. The roof is a gravel covered steel deck roof. The pump house contains water pumps and electrical controls for the cooling tower. A six-cell cooling tower is adjacent to the pump house. It was built in 1981. The 30-foot wide by 120 ft long tower is used to dissipate the heat from the cryogenic compressors in the refrigeration process. The cooling tower is an induced draft cross flow unit with poly fill and wooden decks. Divisions between individual cells are double sided ½ inch plywood on wooden studs. The cooling tower does not contain fire detection nor does it contain a suppression system. The facility will be examined further for the need to install sprinkler protection. The cooling tower is considered a piece of equipment and a Life Safety Analysis has not been performed. Replacement value for the wooden portion of the cooling towers and the fan units (i.e., The concrete basin remains usable) is $300k. Reconstruction will take 6 months.

Building 1005E: Building 1005E is a 4,900 ft^2, 25 ft high one story prefabricated insulated metal skin building constructed on a concrete slab. The facility was constructed in 1981. It is provided with smoke detection, manual fire alarms and bells for local annunciation. Smoke detectors are mounted on pendants dropped from the ceiling to account for smoke layering. This design was based on smoke tests conducted by BNL fire protection engineering in 1980. The fire alarm control panel is located in Building 1006A. Standpipes are provided from the Collider Tunnel. A Fire Department Connection is located at this facility for use in supplementing the tunnel standpipe.

Building 1005E houses the power supplies for a portion of the RHIC injection line at the 6 o'clock sextant. Approximately 6 small power supplies (in the 20kW range) will be located in this facility. In addition, four Blumhein pulsers, each powering an injection kicker magnet, will be located in the structure. Each pulser contains approximately 30 gallons of transformer oil.

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code of Building 1005E were performed as part of the overall RHIC life safety survey.[75]

Building 1007W: Building 1007W (formally known as 1007E) is a 4,900 ft^2, 25 ft high one story prefabricated insulated metal skin building constructed on a concrete slab. The facility was constructed in 1981. It is provided with smoke detection, manual fire alarms and bells for local annunciation. Smoke detectors are mounted on pendants dropped from the ceiling to account for smoke layering. This design was based on smoke tests conducted by BNL fire protection engineering in 1980. The fire alarm control panel is located in Building 1006A. Standpipes are provided from the Collider Tunnel. A Fire Department Connection is located at this facility for use in supplementing the tunnel standpipe system. Equipment similar to that housed in Building 1005E is contained in this Building.

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code of Building 1007W were performed as part of an overall RHIC life safety survey.[76]

RHIC Support Buildings ("B" Series)

At various points around the RHIC, electrical power and control signals are interfaced between cryogenic systems and warm systems. These interface points occur at the "B" series buildings found around the RHIC Ring at 2, 4, 6, and eight o'clock. Each facility contains power supplies, a cryogenic to warm transition point, cryogenic valve boxes, safety system components and beamline instrumentation. Except for 1004B, which contains a mini satellite control room, they perform essentially the same function.

Building 1002B: Building 1002B is a one story 20 ft high prefabricated insulated metal 3,200 ft^2 addition to Building 1002, which is found on the interior of the RHIC Ring. Year of construction is 1995. There is no fire barrier between Building 1002 and Building 1002B. Occupancies of these two areas are to be low fire hazard operations. An interior one-hour fire rated room has been constructed to house control electronics valued at less than $500k. Roof construction is Class I by Factory Mutual Standards. Interior finish has a Class A flame spread rating. Smoke detection has been provided at the ceiling level.

Manual fire alarm pull boxes are located by exits. Combination bell and strobe lights have been installed for local notification. All fire alarm and supervisory devices have been tied back to the BNL Fire/Rescue Group via the Site Fire Alarm System.

Building 1002B receives power from Building 1002A. Some minor corrective measures to the adjacent transformer yard have been funded under a Line Item Project (Job Number 7969, LNI LPU95). Emergency power is provided by generator for lighting. Fire extinguishers are provided throughout the facility to meet NFPA 10.

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code of Building 1002B were performed as part of an overall RHIC life safety survey.[77]

Building 1004B: Building 1004B is a one story 20 ft high prefabricated insulated metal 4,800 ft^2 free standing structure on the outside of the RHIC Ring at the 4 o'clock sextant. Year of construction was 1995. There are no exterior fire exposures for this facility. The exterior electrical structures comply with Factory Mutual Loss Prevention Data Sheet 5-4 for exposure protection. In addition to the standard functions of the "B" buildings, an interior one hour fire rated room has been constructed to house electronics (valued at less than $500k). Its purpose is to act as a remote control room. Due to the use of fibre optics in the RHIC control systems, remote locations can be used to provided full control of the operations. Therefore, Building 1004B is a backup to the control room in Building 1005S. Roof construction is Class I by Factory Mutual Standards. Interior finish has a Class A flame spread rating. The facility is fully sprinklered and fully supervised according to NFPA 13 Standards. Smoke detection has been provided at the ceiling level to protect the high valued power supplies (valued more than $1 million). Manual fire alarm pull boxes are located by exits. Combination bell and strobe lights have been installed for local notification. An independent fire alarm panel has been installed to provide coverage for this facility. All fire alarm and supervisory devices have been tied back to the BNL Fire/Rescue Group via the Site Fire Alarm System.

There are no exposure fire concerns from electrical transformers. Emergency generator power is provided for lighting. The facility complies with Factory Mutual Loss Prevention Data Sheet 5-4. Fire extinguishers are provided throughout the facility to meet NFPA 10.

The descriptions, exiting arrangements, analysis and compliance with the NFPA Life Safety Code of Building 1004B was performed as part of an overall RHIC life safety survey.[78]

Building 1006B: Building 1006B is a one story 20 ft high prefabricated insulated metal 3,200 ft^2 free standing structure on the outside of the RHIC Ring at the 6 o'clock sextant. It was built in

1995. There are no exterior fire exposures for this facility. An interior one-hour fire rated room has been constructed to house electronics (valued at less than $500k). Roof construction is Class I by Factory Mutual Standards. Interior finish has a Class A flame spread rating. Smoke detection has been provided at the ceiling level to protect the low valued electronics (valued less than $500k). Manual fire alarm pull boxes are located by exits. Combination bell and strobe lights have been installed for local notification. An independent fire alarm panel has been installed to provide coverage for this facility. All fire alarm and supervisory devices have been tied back to the BNL Fire/Rescue Group via the Site Fire Alarm System.

Building 1006B receives its power from Building 1006A. There are no exposure fire concerns from electrical transformers. Emergency generator power is provided for lighting. Fire extinguishers are provided throughout the facility to meet NFPA 10.

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code of Building 1006B were performed as part of an overall life safety survey of RHIC.[79]

Building 1008B: Building 1008B is a 3,200 ft^2 free standing, one story 20 ft high prefabricated insulated metal building on the outside of the RHIC Ring at the 8 o'clock sextant. It was built in 1995. There are no exterior fire exposures for this facility. An interior one-hour fire rated room has been constructed to house electronics (valued at less than $500k). The experiment at Building 1008 plans to house several small power supplies within the facility that are valued at less than $100k. Roof construction is Class I by Factory Mutual Standards. Interior finish has a Class A flame spread rating. Smoke detection has been provided at the ceiling level to protect the low valued electronics. Manual fire alarm pull boxes are located by exits. Combination bell and strobe lights have been installed for local notification. An independent fire alarm panel has been installed to provide coverage for this facility. All fire alarm and supervisory devices have been tied back to the BNL Fire/Rescue Group via the Site Fire Alarm System.

Building 1008B receives its power from Building 1008A. There are no exposure fire concerns from electrical transformers. Emergency power is provided generator for lighting. Fire extinguishers are provided throughout the facility to meet NFPA 10.

The descriptions, analysis, exiting arrangements and compliance with the NFPA Life Safety Code of Building 1008B were performed as part of an overall life safety survey of RHIC.[80]

J.2. Fire Risks

The purpose of the fire risk assessment is to evaluate the RHIC Complex vulnerabilities to fire damage. As previously stated, excluded are the major experimental facilities at 1006, 1008, 1012 (1012 is a site for future development) and the smaller experimental areas at 1002, 1004 and 1010. The assessment evaluates the fire risks, protective measures against fire, and level of compliance with DOE fire protection criteria. DOE criteria are outlined in DOE Order 5480.7A, "Fire Protection" and its successor Fire Protection Orders. These criteria address protection of life, of property, to programmatic continuity and to the environment.

Discussion

Tunnels (Excluding Alcoves and Experimental Areas)

The tunnels are one continuous area, only interrupted at each sextant by an Experimental Hall. Any need to of provide a fire barrier at the Experimental Hall interface will be evaluated in the safety analysis of the experiment. Within the RHIC tunnels there will not be many combustible items. The tunnels are corrugated steel and the transition structures are poured concrete. The tunnels contain magnets, cable tray, cables in tray, cryogenic piping and instrumentation. Production cost per magnet is in the range of $150,000. The only exception to the low combustible nature of the facility is the Beam Stop which is discussed below.

The low combustible contents and the nature of slow burning electrical fires will not lead to a fire creating 100% loss in any tunnel segment. There is no continuity of an easily ignited material to propagate flame. The magnets themselves are enclosed in steel cryostats under vacuum. Within the cryostats are layers of aluminized Mylar super insulation. Metal magnet coils are wrapped around a steel beam tube. Magnet coils are epoxy coated, but the ratio of steel to epoxy is very high. These hefty magnets are not subject to exterior fire damage from a low heat output cable tray fire. A tunnel fire involving the IEEE 383 cable in a horizontal tray will likely result in less than 50 linear feet of damage, implying $100k of damage and programmatic interruption less than one month. With the lack of suppression, the Maximum Foreseeable Loss will equal the Maximum Credible loss.

Due to performance and design requirements, the Beam Stops and power supplies on either side of the 10 o'clock area must be close to the magnet string. The design of the power supplies does not contain oil. The loss potentials from an unprotected power supply fire will be approximately $400k.

The frequency of fires in the electrical systems of a well-maintained facility is low, in the order of one in 5 years for a facility of this size.

AGS U-Line

This area is similar to the previously described Collider Tunnel. The principal difference is that only warm magnets are present. The cables are IEEE 383 rated and existing sprinkler protection is provided above the cable tray. These warm magnets are common to the AGS operations and would not be difficult to replace promptly. A fire is expected to develop to a moderate stage before sprinkler head activation (due to the low heat output). However, the loss will be quickly controlled by sprinklers and will not cause extensive damage.

Some of the beamline electronics controlling the U-Line is housed in a small wooden trailer outside of Building 927. This trailer is vulnerable to fire loss due to its combustible construction. The loss potential in dollars is less than $400k, but the programmatic impact of the time to rebuild the equipment and provide suitable housing is the driving factor. It would take four to six months to replace this equipment. In lieu of installing sprinkler protection, the AGS Department has committed to purchasing spare parts to mitigate the time to rebuild the instrumentation in the event of a fire.

Support Structures

Building 1000P: The facility is a noncombustible facility. The power supplies and the instrumentation/control are for the AGS and RHIC portions of the beamline. The power supplies are small (less than 20kW). There are no oil filled devices. The are the only items subject to involvement in a fire is the miscellaneous materials in the facility. The Maximum Credible Fire Loss is equal to the Maximum Possible Fire Loss due to the lack of suppression. In both cases, the loss potential is under $600k (total value of contents, the structure will not receive major damage due to the low heat output). Experience from 30 years of AGS operations has shown that fire in power supplies remains localized unless excessive combustible materials are present. This is not the case for this facility. Equipment is readily available to replace damaged equipment in the event of a fire. The presence of smoke detection is sufficient to meet DOE risk criterion.

Buildings 1002B, 1006B, 1008B: The facility is a noncombustible facility. The power supplies, cryogenic lines, and the instrumentation/controls are the only items subject to involvement in a fire. The Maximum Credible Fire Loss is equal to the Maximum Possible Fire Loss due to the lack of suppression. In both cases, the loss potential is under $500k (total value of contents, the structure will not receive major damage due to the low heat output). Equipment is readily available to replace damaged equipment in the event of a fire. The presence of smoke detection is sufficient for the operation

Building 1004B: The facility is a noncombustible facility. The power supplies, cryogenic lines, and the instrumentation/control are the only items subject to involvement in a fire. The Maximum Possible Fire Loss is estimated at $900k. This is due to the loss of two $200k power supplies and adjacent equipment. Building damage is not expected to be major due to the low heat output by the limited amount of combustibles. The Maximum Credible Fire Loss, the fire with suppression in service and response by the Fire/Rescue Group, is expected to be limited to $200k for equipment. An additional $100k would be incurred for cleanup. The control room is considered a separate fire area due to the one-hour fire rated enclosure. The value and potential loss in this area is less than $200k. The presence of smoke detection and sprinkler protection is sufficient, although sprinkler protection has been provided.

Building 1005S: Building 1005S is a noncombustible facility. The facility is heavily partitioned. The occupancy is mainly offices with limited technician workshop space. The Main Control Room is the most vulnerable of the areas. However, the operation equipment for running the Collider and the Personal Safety System can be reconstructed in a matter of weeks. Due to the serial nature of information from the distributed processing systems, new front ends can be reconstructed in alternate locations. Exact details on what equipment will go into the control room are not available at the time of this report. However current estimates are that the room will not contain more than $500k of equipment.

Building 1005S Cryogenic Wing: This portion of 1005S on the west side is separated from office and shop areas by a two-hour fire rated wall and is being treated as a separate facility. The main hazard in the facility are the oils in the refrigeration mechanisms. These oils are enclosed in heavy metal equipment. The oil is not pressurized. The most likely scenario would be ignition of oil leaking from an enclosed vessel. The facility will be fully sprinklered. The loss potential without sprinklers in-service is $250k (one refrigerator with localized damage). Down time may exceed 6 months as the internal parts of the refrigerators are susceptible to contamination from smokey fires. With sprinklers in-service, the fire will be limited to less than $20k damage with interruption less than one week.

Building 1005H: Building 1005H is the Compressor Facility for the RHIC cryogenic system. The main hazard in the facility are from the compressor oil. These oils are enclosed in heavy metal equipment. The oil is not pressurized. The most likely scenario would be ignition of oil leaking from an enclosed vessel. The facility is fully sprinklered. The loss potential without sprinklers in-service is $250k (largest compressor with localized damage). Down time may exceed 6 months as the compressors are susceptible to contamination from smokey fires. With sprinklers in-service, the fire will be limited to less than $20k damage with interruption less than one week.

Cooling Towers: The cooling towers are combustible, expect for the concrete foundation. In the event of a fire, the Maximum Foreseeable Fire Loss is the same as the Maximum Credible Fire Loss. Total loss of the all six cells can be expected. Property damage is estimated at $375k . Loss time for the reconstruction of the towers would be six months. The likelihood of a fire in these cooling towers is low.

Summary

Area	Loss Potential ($ & Months) Max. Credible Fire (Max. Possible Fire)	Protection Provided
AGS U-Line	$75k/one month ($400k /six months)	Sprinklers, manual alarms
Downstream W-Line, X and Y Lines and Collider Tunnel	$100k/two months (same) $400k/three months by beam stop ($100k/one week)	Smoke detection, heat detection, manual alarms, smoke removal (local suppression/fire barriers by beam stop)
Alcoves	$500k/three Months (Same)	Smoke detection, manual alarms, smoke removal, Vital Spares or suppression
1000P	$600k/one month (Same)	Smoke detection, manual alarms
1002B	$500k/one month (Same)	Smoke detection, manual alarms
1004, A	$600k/3 months	Smoke detection, sprinklers, manual alarms
1004B	$900k/two months ($200k/one week)	Sprinklers, smoke detection, manual alarms
1005H Helium Compressor	$250k/one month ($20k/one week)	Sprinklers, manual alarms
1005S	$500k/one week ($100k/one week)	Sprinklers, elevator lobby smoke detection, control room smoke detection
1005R Refrigerator	$250k/six months ($20k/one week)	Sprinklers and manual alarms
B1005 Cooling Towers	$375k six months (Same)	Internal Cell Divisions of plywood
1006B	$500k/one month (Same)	Smoke detection, manual alarms
1008B	$500k/ one month (Same)	Smoke detection, manual alarms

K. CONVENTIONAL SAFETY OF ACCELERATOR SYSTEMS

The Accelerator Systems Safety Committee has reviewed each major Collider system, in accordance with RHIC OPM 9.1, "Conventional Safety Review of an Accelerator System." Except for high temperature bakeout of the vacuum system, there were no other special hazards identified which resulted in any special controls. An Operating Procedure will provide the administrative controls for vacuum bakeout.

The design and construction of all RHIC systems throughout the RHIC complex (Magnet Electrical, Beam Instrumentation, Vacuum, PASS, Cryogenic, Beam Stop, Control, Injection, RF, Water) is such that no prospective Lockout/Tagout is necessary for routine access to any tunnel or ancillary building. In the Transfer Line, all busswork is covered with engineered barriers. In the Collider, all the high current electrical cabling is cryogenic and therefore barriered by the vacuum jacket. The high current warm to cold transitions are in the Service Buildings where they are barriered. The magnet power supplies are housed in NEMA enclosures. Except for the kicker power supplies, there are no high voltage sources higher than AC power in the Service Buildings or the Collider.

The Injection Kicker uses a high voltage pulsed power supply that is barriered and fenced. Access to the fenced enclosure is controlled by an accountable key lock (Kirk Key). High voltage terminations in the Collider tunnel are barriered.

The high voltage power supplies used by the Beam Instrumentation System are all inherently safe devices. They are currently limited to <10 mA and use high voltage terminations, in accordance with RHIC OPM 5.1.5.0.1, "Supplemental Electrical Safety Standards."

The area around the RF cavities is secured with interlocked gates. The PASS system is used to secure the power supplies for routine access.

In general, access to electrical enclosures for repair or troubleshooting will be controlled by Lockout/Tagout procedures, in accordance with RHIC OPM 5.1.5.1, "Lockout/Tagout." No routine Working Hot is planned.

L. NOISE HAZARDS

Very high noise levels occur in the Compressor Building during operation of the helium turbine compressors (see Appendix 3). Hearing protection and participation in the BNL Hearing Conservation Program is required for personnel who must work in the area for significant lengths of time. Escorted transient access to the area will be permitted, provided hearing protection is worn.

The noise source has been minimized by selection of compressors that provide the lowest noise levels during operation, so that the combination of engineering, personnel hearing protection, training and medical surveillance will minimize the risk of hearing loss.

M. FIRE HAZARDS ANALYSIS OF STAR AND PHENIX

In accordance with the DOE Independent Safety Review of February 18-20, 1998, Fire Hazard Analyses of the STAR and PHENIX experiments and surrounding experimental halls were developed in recognition that they represent large programmatic risk, high dollar value, and contain subsystems that are sensitive to fire damage. The reports and a fire barrier exemption prepared by the S&H Services Division are shown in Appendix 32 and 33. The information in them were also necessary to help define a technical basis to support the DOE Program Secretarial Officer of Energy Research to designate the Hazard Classification of entire RHIC Complex, as “Low Hazard.”

The physics mission of the large detectors does not allow their configurations to be subdivided nor protected by conventional fire protection means. The desired equivalent level of protection is achieved by a systematic reduction of combustibles, limitation of ignition sources by overcurrent protection, in most cases to board level, and interlocks to electrical power with highly sensitive smoke detection. The most likely form of ignition is from electrical sources. This approach results in risk reduction to the lowest practical level.

The FHA is being used as a vehicle to document exemption requests to DOE. The halls that contain the large detectors each represent areas where over 50 million dollars of value are installed. The Collider Tunnel house similar values. The policy DOE requires areas with values over 75 million dollars to be subdivided for fire protection. Due to the low combustible loading inside the Collider tunnel within the tunnel, only smoke/ODH barriers were installed instead of permanent firewalls.

Based on the findings of the PHENIX DBA analysis it is desirable to not have a barrier between the Collider Tunnel and the IR.

One concept accepted by DOE is to allow conventional electrical equipment within regions susceptible to exposure of combustible gas (a NEC Class I Division II area). To mitigate the explosion hazard, detection of flammable gas at or above 25% of the LEL is interlocked with the electrical power to remove ignition sources, emergency ventilation fans are turned on and automatic purge of the detectors with noncombustible gas is automatically initiated. The collective result of these actions will remove the explosion hazard and keep the experimental hall in a safe state. Flammable gas will be monitored independently by PASS and by the detector equipment protection systems. Testing of the PASS flammable gas monitors shall be conducted as part of the routine PASS testing per Accelerator Safety Envelope 5.C.1.

Based on the FHAs and the safety analysis in Chapter 4, the DOE concurred with the risk exposure and level of protection.

N. RISK ASSESSMENT

The principal risk considerations related to the RHIC facility are fire, explosion, radiation, electrical, noise and cryogenic hazards. A risk assessment of the RHIC Complex is based upon a methodical review of individual hazards that are examined before and after mitigation for severity, probability and risk category. BNL ES&H Standard 1.3.3 provides the methodology to conduct the assessment. A summary of the systems and hazards is shown in Table 4-N-1.

Note that the terminology used for the SAD in this section relates to a BNL definition in ES&H Standard 1.3.3, which differs from that in DOE O 420.2. The Hazard Assessment Matrix is a tool to define the level and rigor of safety documentation. The aforementioned DOE order requires safety documentation that is equivalent to the definition of a Safety Analysis Report in ES&H Standard 1.3.3. This ES&H Standard was based on DOE O 5481.1B and Military Standard 882B. The hazard categories in ES&H Standard 1.3.3 also differ from the language in DOE O 5481.1B for Hazard Classification. The Hazard Classification of the RHIC Complex has been designated “low” based on minor onsite and negligible offsite consequences to personnel or the environment.

TABLE 4-N-1

Summary of Risk Analyses by System and Hazard

SYSTEM	HAZARD
RHIC Complex, Except Large Detectors	Fire/Explosion
RHIC Complex	Electrical
RHIC Complex	Residual Radiation Exposure
Beamline Enclosures	Prompt Radiation
Cryogenic System	Release of Helium Gas
Helium Compressor, Cryogenic Refrigerator and Valve Boxes, Helium Storage System Compressor 1005E	Fire
Helium Compressors	Noise
Injection System Magnets	Fire
U-, W-, X- and Y-Line Power Supplies	Fire
Main Magnet Power supply in Service/Support Buildings	Fire
RF System	Fire
Magnet Power Supplies and Transformer - Large Detectors	Fire
Gas System - Large Detectors	Explosion/Fire
Experimental Electrical Equipment - Large Detectors	Fire
Large Detectors - RHIC Complex	Natural Phenomena
Collider Beam Stops and Limiting Aperture Collimators	Induced Activity in Soil and Groundwater

SYSTEM: RHIC Complex, Except Large Detectors

HAZARD: Fire/Explosion

Event:	Fire
Possible Consequences & Hazards:	Injury or Fatality Damage to Equipment
Potential Initiators:	Natural Phenomena, Human Error, Equipment Failure

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Fire Detection and Alarms Fire Suppression Standpipe in Collider Tunnel Emergency Ventilation Compliance with NFPA 101 Design Criteria RHIC Access Safety Training

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: RHIC Complex

HAZARD: Electrical

Event:	Electric Shock, Flashover
Possible Consequences & Hazards:	Exposure to Lethal Voltage, Flashover from a Short, Exposure to Low Voltage High Current Buss
Potential Initiators:	Human Error, Equipment Failure

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Compliance with NEC Lockout/Tagout Hardware and Procedures Interlocks via PASS Electrical Safety Training Working Hot Procedures/Permits Safety Committee Reviews of Equipment Not Covered by the NEC RHIC OPM 5.1.5.0.1 Supplemental Electrical Safety Standards

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: RHIC Complex

HAZARD: Residual Radiation Exposure

Event:	Exposure to Activated Material
Possible Consequences & Hazards:	Violations of Administrative or Regulatory Requirements
Potential Initiators:	Failure to Follow Administrative Procedures

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Radiation Worker Training Radiation Work Permits ALARA Reviews of Equipment Designs Posting

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Beamline Enclosures

HAZARD: Prompt Radiation - Inside Enclosures

Event:	Beam Restored in an Occupied Enclosure
Possible Consequences & Hazards:	Prompt Radiation Exposure to Personnel Inside a Beam Enclosure from accelerated beam or x-rays from the RF System.
Potential Initiators:	Failure of PASS System

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Radiation Interlocks to Critical Devices Locked Gates Key Trees Sweep Procedures Area Monitoring Shielding Visual and audible Alarms RHIC Access Safety Training Access Control Procedures

Risk Assessment Following Mitigation - Inside Beam Areas						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Beamline Enclosures

HAZARD: Prompt Radiation - Outside Enclosures

Event:	Beam Loss During Operation
Possible Consequences & Hazards:	Prompt Radiation Exposure to Personnel Outside a Beam Enclosure
Potential Initiators:	Uncontrolled Loss of Collider Beam

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Radiation Interlocks to Critical Devices Sweep Procedures Area Monitoring Shielding Visual and audible Alarms RHIC Access Safety Training Access Control Procedures

Risk Assessment Following Mitigation - Outside Beam Areas						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Cryogenic System
HAZARD: Release of Helium Gas

Event:	Loss of Helium Gas
Possible Consequences & Hazards:	Asphyxiation Freezing Hazard
Potential Initiators:	Pipe Break, Natural Phenomena, Equipment Failure

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Compliance with ASME Pressure Vessel Code, Section VIII PASS Monitoring of Oxygen Levels Emergency Ventilation RHIC Access Safety Training

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Helium Compressor, Cryogenic Refrigerator and Valve Boxes, Helium Storage System Compressor 1005E

HAZARD: Fire

Event:	Electrical Fire
Possible Consequences & Hazards:	Component Failure $30M Divided Between Building 1005R and 1005H (See Cryogenic System for analysis of Helium Gas Hazards)
Potential Initiators:	Equipment Failure, Human Error

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Fire Detectors, Alarms and Suppression Onsite Fire Department Firewall Between 1005R and 1005S

Risk Assessment Following Mitigation - Hardware						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Helium Compressors

HAZARD: Noise

Event:	Exposure to Noise
Possible Consequences & Hazards:	Noise in Compressor Buildings, 1005H, 1005E
Potential Initiators:	Entry Without Hearing Protection

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Hearing Conservation Program Hearing Protection

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Injection System Magnets

HAZARD: Fire

Event:	Fire in Magnet
Possible Consequences & Hazards:	Loss of $300k/One Month, $900k/Three Months Near W-Line Beam Stop
Potential Initiators:	Equipment Failure, Human Error, Loss of Cooling Water, Short in Coil

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Sprinklers in the U-Line Standpipes in the W-, X- and Y-Lines Fire Detection and Alarms Temperature and Cooling Water Interlocks IEEE 383 Cable Onsite Fire Department Limited Combustible Contents Onsite Fire Department

Risk Assessment Following Mitigation - Single Magnet						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Risk Assessment Following Mitigation - String of Magnets						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: U-, W-, X- and Y-Line Power Supplies

HAZARD: Fire

Event:	Electrical Fire
Possible Consequences & Hazards:	Loss of $30k/Supply, $115k/Kicker Supply
Potential Initiators:	Equipment Failure, Human Error, Loss of Cooling Water

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Fire Detection and alarms Onsite Fire Department IEEE Cable Limited Combustible Contents

Risk Assessment Following Mitigation - Single Magnet Power Supply						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Risk Assessment Following Mitigation - Single Kicker Power Supply						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Risk Assessment Following Mitigation - Group of Power Supplies						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Main Magnet Power Supply in Service/Support Buildings

HAZARD: Fire

Event:	Electrical Fire
Possible Consequences & Hazards:	Loss of Transformer in Substation Dipole Ramp PS $375k Dipole Flattop PS $200k Main Quadrupole PS $275k Bypass Quadrupole PS $90k
Potential Initiators:	Equipment Failure, Human Error

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Fire Detection, Alarms and Suppression Onsite Fire Department Maintenance of Substation IEEE Cable Limited Combustible Contents

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: RF System

HAZARD: Fire

Event:	Electrical Fire		
Possible Consequences & Hazards:		Acceleration	Storage
	Cavities	4 @ $400k	10 @ $125k
	PA and Drivers	4 @ $110k	10 @ $110k
	Other	$225k	$200k
Potential Initiators:	Equipment Failure, Human Error		

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Fire Detection and Alarms Fire Suppression in Power Supply Building Standpipe in Collider Tunnel Water Temperature and Flow Interlocks Onsite Fire Department

Risk Assessment Following Mitigation - Single Component						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Magnet Power Supplies and Transformer - Large Detectors

HAZARD: Fire

Event:	Electrical Fire Magnet Power Supplies or Transformers
Possible Consequences & Hazards:	Loss of Magnet Power Supply
Potential Initiators:	Equipment Failure (Electrical or Mechanical), Human Error, Network Phenomena

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Built to NEC and IEEE Codes Routine Maintenance Program Control of Combustibles in Area Fire Detectors, Alarms

Risk Assessment Following Mitigation - Power Supply						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Gas System - Large Detectors

HAZARD: Explosion/Fire

Event:	Gas Explosion/Fire
Possible Consequences & Hazards:	Fire Damage to Experimental Equipment and Facility Injury or Fatality
Potential Initiators:	Equipment Failure (Mechanical and Electrical) Electrical Short, Human Error, Natural Phenomena

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Gas system Safety Interlocks Gas Detectors Breakers and Fuses Electrical Interlocks Purge of Experimental Equipment with Inert Gas Systems Designed and Operated in Accordance with Codes and Standards Safety Committee Reviews Administrative Controls Training of Personnel

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Experimental Electrical Equipment - Large Detectors

HAZARD: Fire

Event:	Fire in Experimental Equipment in Experimental Area
Possible Consequences & Hazards:	Flammable Gas Explosion Injury or Fatality Damage to Experimental Equipment and Facility
Potential Initiators:	Equipment Failure (Electrical and Mechanical), Loss of Cooling Water, Human Error

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Interlocks (Mechanical and Electrical) Fuses, Breakers, etc. Fire Detection, Alarms, Suppressing System Purging Experimental Equipment with Inert Gas Training of Personnel Safety Committee Reviews Built to Industry Codes and Standards

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Large Detectors - RHIC Complex

HAZARD: Natural Phenomena

Event:	Natural Phenomena
Possible Consequences & Hazards:	Equipment Failure Personnel Injury Facility Structural Failure Electrical Fault
Potential Initiators:	Earthquake, Hurricane, Flooding

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Experimental Equipment Designed to Codes and Standards

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

SYSTEM: Collider Beam Stops and Limiting Aperture collimators

HAZARD: Induced Activity in Soil and Groundwater

Event:	Secondary Radiation in Soil
Possible Consequences & Hazards:	Contamination of groundwater with tritium and ^{22}Na
Potential Initiators:	"Washout" of radionuclides into the groundwater by rainwater.

Risk Assessment Prior to Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

Hazard Mitigation:	Groundwater Monitor Close to Beam Stops Surface Soil Sampling Geomembrane Over Beam Stop

Risk Assessment Following Mitigation						
Severity:	I. Catastrophic	II. Critical	III. Marginal	IV. Negligible		
Probability:	A. Frequent	B. Probable	C. Occasional	D. Remote	E. Extr Remote	F. Impossible
Risk Category:	1. High Risk	2. Moderate	3. Low Risk	4. Routine		

O. STAR DETECTOR

1.0 Introduction

Most hazards posed by the operation of the STAR detector are conventional ones normally associated with an industrial environment. The hazards in this category include electrical hazards, conventional hazards and hazardous and toxic materials. The unusual hazards posed by the operation of the STAR detector include flammable gas hazards, magnetic fields, oxygen deficiency, radiation and lasers. Table 4-O-1 summarizes the hazards associated with the STAR detector.

None of these pose an on-site impact capable of damaging a sufficient portion of the facility so that it cannot be returned to the operational state. However, if no action is taken concerning the control and mitigation measures outlined in this document, the hazards do have the potential for causing serious injury to personnel and costly damage to the detector and its supporting equipment. The analysis of the STAR detector, along with its supporting documentation, demonstrates that the STAR detector conforms to the applicable criteria in the Brookhaven ES&H Manual, Brookhaven Radiological Control Manual, RHIC Project OPM, applicable national design or safety codes, and Department of Energy Orders shown in Table 1-A-2. Conformance with these standards will reduce the potential for an incident such that no more than minor on-site and negligible off-site impacts to people or the environment are possible.

1.1 Flammable Gas Hazards

Potential flammable gas hazards result from the utilization of methane or other flammable gases in the Time Projection Chamber. These hazards are assessed and the provisions adopted for their abatement and control are described in Section 2.2.

1.2 Electrical Safety

Potential electrical hazards (and some of the fire hazards of the facility) associated with operation of the STAR detector are: (i) the high-voltage, high-current DC power supply and distribution system associated with the solenoidal magnet used in STAR, (ii) the low-voltage, high current electrical power systems associated with signal collection, monitoring and data processing

TABLE 4-O-1

Overview Hazards Associated with the STAR Detector System

Subsystem (Reference)	Hazard Type	Detection	Mitigation
SVT (2.1.3.1)	Electrical (HV)	NA	Use of rated cables Use of rated connectors Barriers Procedures
	Electrical High Current	Computer monitoring	Use of rated cables Use of rated connectors Fusing
	Material Beryllium	NA	Inaccessible location Training Secured Storage
	Water Leaks	Leak detection Flow monitoring	"Leakless" system Low flow rate
	Vacuum Pipe	NA	Procedures Training Mechanical tooling
TPC (2.2.3.1)	Flammable Gas	Flammable gas detection in gas mixing room, and around detector. Gas monitoring of insulating gap gas exhaust. Oxygen monitoring of TPC gas exhaust.	Hardware interlocks. Runs at 1 atm. Pressure. Low gas leak rate. Forced air ventillation. Limited supply of gas.
	Electrical (HV)		Current limiting Use of rated cables Use of rated connectors Procedures Training
	Electrical High Current		Use of rated cables. Use of rated connectors.
	Laser Hazard		Beams normally enclosed in enclosures requiring a tool to open. Commercial laser system interlock. Laser Training Procedures PPE (safety glasses) when working with exposed beams.
	ODH (working inside TPC)	Oxygen measurement prior to entry.	Forced air ventilation. Gas supply locked out. Power locked out. Training. Procedures.

Subsystem (Reference)	Hazard Type	Detection	Mitigation
Magnet (2.4.3.1)	Electrical (HV)		Over current protection. Use of rated cables. “Dead front” designed equip.
	Electrical High Current		Barriers. Appropriate signage. Accountable key lock (Kirk Key). Training. Procedures. Interlock system.
	Magnetic Fields	Magnetic field (Hall probe)	Barriers. Appropriate signage.
	Mechanical: Magnet Movement		Procedures. Training. Barriers.
EMC (2.5.3.1)	Mechanical: Module Installation		Special tooling. Procedures training
	Electrical (HV)		Current limiting. Barriers. Training Appropriate signage.
	Electrical (AC)		Use of rated cables. Use of rated connectors. Training.
	Material (Pb)		Encapsulated. Procedures.
	Fire (Plastic)	STAR HSSD system. Building HSSD system.	Limited oxygen access. Thermal ballast of Pb.
FTPC (2.6.3.1)	Electrical (HV)		Use of rated cables. Barriers. Appropriate signage. Procedures. Training. Current limiting.
	Laser		Beams will normally be enclosed in barriers, which require a tool to open. Training. Procedures. Commercial interlock on laser.
Trigger (2.7.3.3)	Electrical (HV)		Use of rated cables. Use of rated connectors. Barriers.
	Fire (Plastic)	STAR HSSD system. Building HSSD system.	Limited oxygen access. Current limits.
Shield Wall (2.9.1.1)	Radiation Collider Related	Radiation detectors (e.g., chipmunks)	Concrete shield wall. Personnel access labyrinths. PASS system. Access restrictions. Training.

from the STAR detector systems, (iii) the high voltage power supplies and distribution systems providing operating voltages to detector elements and (iv) 480/120V 60 Hz and 13.8 kV power distribution. These potential hazards are assessed in detail in Section 4 for each subsystem of the STAR detector where the provisions for their abatement and control are described.

1.3 Fire Prevention/Detection/Suppression

Fire prevention, detection and suppression systems associated with the facility or its buildings are provided as part of the RHIC infrastructure. Fire prevention, detection and suppression systems associated with the detector, are discussed in Chapter 3, Section 2.3 and Appendix 32, Fire Hazard Analysis - 1006 and the fire barrier exemption in Appendix 33.

1.4 ODH and High-Pressure Hazards

The possible oxygen deficiency hazard (ODH) associated with the malfunction of the TPC and systems used to "inert" the detector are discussed in Section 2.2. ODH involved with a malfunction of the super-conducting magnets in the areas adjacent to the STAR experimental area are prevented from impacting the Wide Angle Hall (WAH) with the installation of barriers. Possible ODH and high-pressure hazards in conjunction with the TPC gas mixing and storage areas are described in Section 2.2.

1.5 Radiation Hazards and Radiation Shielding

The principal radiation hazards occur due to operation of the RHIC accelerator. The major potential hazard is associated with the loss of circulating beam in a machine magnet and the subsequent cascade of particles produced in the components surrounding the primary ion beams and in the accelerator enclosures immediately upstream and downstream of the WAH.

Access control procedures, radiation interlocks, radiation shielding and personnel training are employed to protect personnel from possible exposure to beam radiation in the primary beam enclosures (including the WAH area).

An assessment of the radiation shielding in the STAR WAH is given in Chapter 4, Section O, Subsection 2.9. An important radiation shielding design goal was to construct the area such that all service buildings and unfenced outdoor areas immediately adjacent to the beam shielding at the STAR WAH can be designated as uncontrolled areas where unrestricted occupancy may be permitted.

1.6 Conventional Hazards

The conventional safety hazards associated with the STAR facilities do not differ in magnitude or kind from the conventional safety hazards encountered in other BNL accelerator experimental areas or activities in industrial and commercial business settings nationwide. Included under the heading of conventional hazards are industrial safety, including mechanical safety, for which applicable OSHA regulations are enforced: traffic safety, severe weather, industrial hygiene, over exertion, slips, trips, and falls.

1.7 Hazardous and Toxic Materials

Design and fabrication of the STAR detector has incorporated a conscious effort to avoid the use of hazardous or toxic materials wherever practical. In cases where it is found necessary to use hazardous/toxic materials for technical reasons, (e.g.; beryllium for the beam pipe and Silicon Vertex Tracker (SVT) components), procedures will be implemented to minimize the exposure of personnel and to satisfy or exceed the requirements of federal and New York State laws, regulations and orders, Brookhaven ES&H Manual and RHIC OPM.

1.8 Impact on People and the Environment

With the exception of the potential radiation and ODH hazards associated with the operation of the STAR detector, all the facilities and operation activities associated with the STAR Detector are characterized as being similar to existing technology or to industrial or commercial facilities with a long history of accident-free operation. These hazards present minor on-site and negligible off-site impact to people and the environment.

1.9 Administrative Control, Enforcement and Training Requirements

Enforcement of administrative controls, procedures and personnel training requirements are an essential component in ES&H performance. Regular inspections and appraisals by the RHIC ES&H Staff are a critical part of this process and will play a major role in the evolving safety program of the STAR project. In addition, training is required for workers at STAR. Detailed records will be kept of personnel training and operations will be restricted only to trained and qualified individuals. The training plan for the Project will address, environment, safety and health requirements in accordance with RHIC OPM 5.7.0.0 ES&H Training.

1.10 Design Basis Accidents for the TPC

1.10.1 Postulated Accident

The TPC is operating in the wide angle hall with voltage on the field cage and P10 flowing in the chamber. Cooling air is flowing through the volume between the inner field cage and the SVT cone. The beam pipe collapses and throws part of the SVT cone into the inner field cage creating a one foot diameter hole. The loss of TPC gas pressure automatically puts the gas system into purge mode and argon flows into the TPC at a flow rate of 200 liters/min forcing P10 out the rupture at the same rate. The P10 is swept away by the cooling air flowing by at 0.25 m/sec. A flammable mixture forms at the boundary layer and is ignited by a spark between the field cage and the shattered SVT cone.

1.10.1.1 Consequences

Since the P10 flows into a relatively high velocity air stream it is assumed that the P10 will burn much like a forced air furnace burner with 100% combustion of the methane in the leaking P10 stream. The flame, if it can actually sustain its self, will produce heat at a rate of 42,000 BTU/hr.[1] The flame could burn for between 26 minutes and 125 minutes depending on where reality lies between two limiting models (see calculations in the next section). The heat output of the flame is one quarter of an industrial strength portable space heater[2] and may ignite the inner field cage, Beryllium beam pipe, SVT, SSD, SVT cone and wiring and the front end electronics on one end of the TPC. Smoke damage would probably destroy the TPC sectors and the outer field cage.

- Offsite effects – none
- Non-project personnel effects – none
- Project personnel effects – possible toxic hazard from burned Beryllium beam pipe and burned SVT Beryllium parts.
- If ignition does not occur the rapidly moving cooling air volume (11,000 liters/min) will dilute the P10 outflow to 4%, well below the lower flammable limit of 50% P10 – 50% air.[3]

Note: P10 is a mixture of 90%Argon and 10%Methane. It is considered non flammable by the Department of Transportation and is described in the MSDS as “Non Flammable, will not support combustion." However, tests have shown that it can burn under some circumstances so it seems reasonable to consider worst case consequences of an accident.

1.10.1.2 Engineering Controls

Smoke detectors in the wide angle hall will:

- Cause a power shutdown, turning off the cooling air passing by the inner field cage rupture. This will reduce the local intensity of the flame and will probably either move the flame to outside of the inner field cage volume or cause it to extinguish.
- Start ventilation blowers which will help clear the air in the wide angle hall. If gas escapes, unburned, then flammable gas detectors on the TPC will also trigger the ventilation blowers mentioned above.

1.10.1.3 Failure Mode and Effect Analysis

See Appendix 30.

1.10.2 Postulated Accident Two

The TPC is operating in the wide angle hall with voltage on the field cage and P10 flowing in the chamber. As a result of an unknown scenario, the 50 m^3 of P10 in the TPC is released to the volume of the Wide Angle Hall (WAH). By some unknown process, this entire 50 m^3 of P10 is mixed with the air in the WAH to form the stoichiometric composition of 51% by volume of P10 in a P10-air mixture. The total volume of this P10-air mixture is 97.1 m^3 (50/0.51 m^3). This volume of P10-air mixture is then ignited. The calculations relevant for this postulated accident are included in Appendix 49 to this document.

1.10.2.1 Consequences

As explained in Appendix 49, when the P10-air mixture is ignited the result is a deflagration which is not accompanied by generation of a significant pressure wave. Please refer to Fig. 3-J-3 for a schematic of the WAH and the removable radiation shield wall.

Under conservative assumptions, if the detector were residing in the WAH, with the radiation shielding wall in place, the resulting overpressure in the WAH would be ~1.1 psi. An analysis has been done to investigate the consequences of this overpressure on the structure of the WAH and on the removable shield wall that separates the WAH from the STAR Assembly Building (AB). The conclusions reached are that an overpressure of this magnitude would not damage the WAH structure, nor would it be sufficient to topple or slide the shield wall.

If the detector were residing in either the WAH or the AB, with the shield wall not in place, the resulting overpressure was calculated to be ~0.4 psi. This pressure may be sufficient to cause some damage to the AB structure. It is conceivable that this structural damage could result in injuries to personnel.

An estimate was also made of the possibility and severity of burns to personnel in the area around or within the burning volume of P10-air mixture. It was concluded that serious burns should be limited to the region of the burning mixture.

- Offsite effects - none
- Non-project personnel effects - none
- Project personnel effects - possible burns, possible injuries do to structural failures of Assembly Building.

1.10.2.2 Engineering Controls

Flammable gas detectors mounted inside, and just outside, of the STAR detector will cause a power shutdown, reducing the possible ignition sources. These detectors will also alarm personnel.

Monitoring of the input and output gas flows to the TPC will alert personnel of any change in the leak rate from the TPC.

Monitoring of the Oxygen content of the return gas from the TPC should detect the presence of any leak in the TPC gas volume.

1.11 Applicable Safety Codes and Standards

1.11.1 Overview

The STAR detector has been designed, constructed and will be operated in compliance with applicable federal, state and local laws, orders and regulations, industry codes and standards, BNL Environment, Safety and Health Manual (ES&H Manual), Radiological Control Manual and Section 5 (Generic ES&H Procedures) of the RHIC Operations Procedures Manual (OPM).

Additionally STAR project management has established a set of standards and guidelines to be utilized in the course of the design of the project.

STAR Note # 93 “STAR General Guidelines for Design Review”

STAR Note # 105 “STAR Mechanical Design Standards and Guidelines”

STAR Note # 143 “Electrical Safety Reference Documents”

In addition to recommendations and/or requirements specified in DOE, BNL ES&H Manual and RHIC OPM, the applicable criteria in Table 1-A-1 were used in the design, procurement, and construction of the STAR detector.

1.11.2 Design Reviews

STAR project design review procedures are listed in STAR Note #93 “STAR General Guidelines for Design Reviews”. Designs, fabrication, installation, and test of experimental detector systems and ancillary support systems have been subject to internal design reviews. The design review teams have been comprised of competent panels, appropriate to the particular system and/or subsystems under review. Additionally a standing RHIC Experimental Safety Committee, Radiation Safety Committee, Laboratory Electrical Safety Committee or specifically charged sub-committees, appointed by RHIC and BNL management, have reviewed various aspects of the STAR detector.

2.0 Safety Analysis

2.1 Silicon Vertex Tracker (SVT)

2.1.1 Overview

The Silicon Vertex Tracker (SVT) is a high resolution solid state tracking device. The SVT is a segmented annular cylinder through which the beam pipe passes. There are three layers of detectors. The SVT is supported by an epoxy composite support cone which is supported from the TPC end rings.

Silicon drift detectors are mounted in ladders supported at the center of the STAR detector.

Front end electronics are integral to the SVT. Preamp/shaper amplifiers and Switched Capacitor Array integrated circuits are included in custom hybrid circuits adjacent to the Si detectors. Copper/kapton cables connect the hybrids to transition printed circuit cards at the support/water manifolds at each end of the detector. Conventional cables connect the transition cards to the read-out electronics mounted at the ends of the TPC in read-out modules electrically isolated from the TPC.

Interface/support beams are connected to the support cones. The support cones have flanges that connect to the TPC. The ladders and endcaps of the SVT will be made of beryllium and the water channels for cooling the hybrid electronics will also be made of beryllium. The detectors are fabricated from Si wafers. The SVT will be clamped clam shell fashion around the beam pipe and will be installed inside the TPC inner field cage.

Power must be brought into the SVT. The total power input to the SVT including read-out electronics will be less than 5000 watts.

Cooling of the SVT detector based electronics will be by recirculating water in a “leakless” cooling system. The system is called leakless, since it operates at less than atmospheric pressure. If a leak develops, air bubbles into the system, but water does not drip out. Cooling of the SVT read-out electronics will be by water from the TPC FEE cooling system. Cooling of the Si detectors will be by conditioned air.

Where possible, non-metallic material used in the SVT will be non-flammable or fire resistant to the extent that the material will not continue to burn when the source of ignition has been removed.

For the whole SVT system, conformance to the NFPA-70 (NEC), as well as applicable DOE orders, RHIC OPM (sec. 5.1.5.0.1) and BNL ES&H Manual (sec. 1.5) will be required.

2.1.2 Safety Analysis

2.1.2.1 Hazards

<u>Electric Hazards from Use of High Voltage (HV) to Bias the Detectors</u>

The principle electric hazard arises from the need for a high voltage gradient-induced drift field in the Silicon Drift Detectors. The highest bias will be 1.5 kVDC. The maximum current for the High Voltage supplies is less than 9 ma. The high voltage will be carried from power supplies located in the support electronics racks to the Read-out Modules at the TPC end rings via tray-rated red RG-59 cables in cable trays with SHV connectors at both ends . The cables, trays and connectors will meet or exceed the requirements specified in the RHIC Project OPM (sec. 5.1.5.0.1).

Smaller diameter high voltage rated cables will be used along the SVT support cones. From the transition card at the cooling manifold to the ladders, the SVT will use high voltage insulated and rated copper cables, which meet the RHIC and BNL safety standards.

SVT low voltage electrical systems (e.g. FEE) will be powered using low voltage power supplies. The primary hazards in such systems are damage from high fault currents.

Such hazards can be reduced to a low level of risk by requiring conformance to the NFPA-70 (NEC) and applicable DOE orders for experimental facilities and applicable sections of the BNL ES&H Manual (section 1.5.2) and RHIC OPM (section 5.1.5.0.1). In the case of low voltage, high current power distribution systems like those used to power electronic systems, the RHIC OPM defines a high current power source as one with a designed or rated current exceeding 10 amps. For such electrical systems, the RHIC OPM (5.1.5.0.1) requires that the electrical conductors between a low voltage, high current power source and one or more electrical loads (1) have power source over-current protection, (2) be correctly sized to carry current from source to load under any conceivable fault condition, (3) have proper connections to multiple loads, (4) have connectors that are appropriate for carrying the expected current, and (5) have equipment for monitoring to detect fault conditions and control systems to shut down high power crates when such conditions are detected.

The SVT will use 6 conductor 12 AWG PLTC rated tray cable , each conductor carrying less than 5 amps. Each conductor will be fused at the power supply. Since the conductors are sized to minimize voltage drop, ampacity is more than adequate. All connectors are sized appropriately. The power supplies are ferroresonant and are current self-limiting. Power supply monitoring at the read-out modules will be used to detect more subtle problems.

The SVT signals will be taken off via twinax cables.

The low voltage power will be routed from the read-out modules to the transition cards via multiple cables.

<u>The Use of Beryllium and Beryllia</u>

Beryllium is used in the support structure. Beryllia is the substrate of the front end electronics hybrids. The use of beryllium and beryllia place restrictions on the handling and maintenance of the SVT.

The presence of beryllium and beryllia is mitigated by the fact that the detector is inaccessible when installed. Contact with the beryllium will only be made if the detector has to be removed from its operational location. It is expected that detector removal will occur at most once per year during STAR down time. Routine handling will not require any contact with the beryllium structure. All personnel needing to handle the beryllium structures will be trained in the safe handling of beryllium.

When outside the detector, the SVT assembly will be stored in a locked facility with controlled access. In addition, all beryllium material not part of the SVT assembly will be kept in a locked storage cabinet. The cabinet will be posted to indicate the presence of the beryllium.

The Possibility of Water Leaks

The presence of water in the system for cooling the electronics carriers presents a hazard due to water leaks. This potential hazard is mitigated by the fact that a leakless, sub-atmospheric pressure system will be used. The SVT water system includes inlet/outlet circuits that can be isolated by appropriate valving. The flow rate of the water will be moderate (less than 20 gal/min) , and the beryllium cavities carrying the water through the detector will be sealed and treated to prevent corrosion and leaks. The water temperature and pressure will be monitored by the STAR Controls System and a water flow/power supply interlock will be provided.

In addition, the STAR detector will include a water detection system (manufactured by Tracetek) that will include sensing in the area of the SVT water manifolds which are located on the TPC end wheels and on the manifolds located at the SVT detector.

Proximity of the SVT to the Beam Pipe and the TPC

The detector is in close proximity to the RHIC beam pipe and other STAR detector systems. The innermost SVT detector layer is at a radial distance of just 18 mm from the beam pipe. Since there are potential hazards from the beryllium material of the beam pipe, the fragility of the beam pipe, and the implosion hazard, personnel working on the SVT will be fully trained and supervised during work near the beam pipe area. Removal of the detector will require formal procedures (clam-shell opening, pulling of cables, mounting of removal jig etc.).

The SVT support cones will include a support mechanism for the beam pipe that will prevent contact between the beam pipe and the SVT.

Due to the high possibility of damage to adjacent systems as well as the SVT, working hot on the SVT while installed in STAR will be prohibited.

Other Hazards

The SVT utilizes low power lasers and sealed radioactive sources during calibration off line. Neither lasers nor radioactive sources are used when the SVT is installed in the detector. The SVT does not use flammable gas.

2.1.2.2 Safety Systems

The SVT includes a local interlock system to provide hardware protection.

Detection

Local hardware interlocks exist for:

Low Voltage power supply over-temperature.

High voltage power supply over voltage and over-current.

SVT cooling water flow and temperature.

SVT cooling air flow and temperature.

Hardware Interlocks to/from Other Star Sub-Systems

Status of the TPC FEE water is available from the TPC interlock system. The SVT requires this interlock to guarantee cooling water for the SVT RDO electronics.

Status of SVT air is available to the TPC interlock system. The TPC may choose to interlock the TPC air system to the SVT air to prevent over or under pressure conditions at the inner field cage.

Software Monitoring

While software monitors are never a primary protection device, here they serve to enhance the protection of the SVT by giving early warning of developing potentially damaging conditions. These monitors include:

Detector temperature, and

Low voltage power supply voltages and currents

Mitigation

Local interlocks will be used to shut down or modify operation of the SVT to protect the hardware.

The SVT will require a hardware permission from STAR to operate low voltage power supplies.

The SVT will require a hardware permission from STAR to operate high voltage power supplies.

Monitoring of voltages, temperatures, etc. will be used to identify dangerous trends that might become damaging to allow corrective actions to be taken to prevent damage.

Administrative Controls

Working hot will not be allowed on the SVT when it is in its operational position.

2.1.3 Modes of Operation

The SVT will be operated on the bench in the SVT assembly room and SVT electronics lab.

The SVT will be operated in place at the interior of the STAR detector.

2.1.4 Assembly and Maintenance

The Si detectors, front end hybrids and hybrid cables will be assembled into ladders which facilitate testing and replacement. Thirty six ladders will be assembled into the two clamshell halves that make up the SVT. The two clamshell halves will then be installed into the main support cones of the SVT. Custom support fixtures and transporting devices will be used to move and install or remove the SVT. Guide structures built into the TPC supports will guide the cones and the SVT into position during installation and removal.

2.1.5 Emergency Procedures

In the event of fire, power crash off incidents, or other catastrophic events, all power to the SVT may be removed without delay.

2.1.6 Maintenance

No maintenance of the SVT itself is anticipated while installed in the detector. If repair or replacement of components of the SVT are required, the SVT will be removed from the detector and the repair will take place in the SVT assembly facility.

Defective read-out modules will be removed as modular units and replaced with qualified spares.

Special approval and operating procedures will be required if diagnostic analysis of the SVT is required in place or partially removed from the TPC.

2.1.7 Training and Qualifications

In addition to the training described in section 1.9, the staff members will receive formal BNL training as appropriate for their work assignments.

2.2 Time Projection Chamber (TPC)

2.2.1 Overview

The TPC provides electronic tracking of charged particles radiating from the heavy ion collisions at RHIC. Measurement of track curvature in the magnetic field and the dE/dx (energy loss) provide particle identification and momentum determination.

The TPC is a cylindrical structure 4.1 meters in diameter and 4.6 meters long with a mass of approximately 11,400 kg. This structure consists of three concentric cylinders that are held in position by an aluminum "wheel" at either end. The outer cylinder, or gas vessel, consists of 2.5 mm aluminum skins bonded to a 5 mm aluminum honeycomb core. An annular gap of 5.7 cm separates the gas vessel and outer field cage cylinders. The field cage consists of etched copper/kapton flexible circuit board material bonded to either side of a nomex honeycomb core. The copper/kapton of the field cage is etched to form copper electrode rings 1 cm long on a 1.15 cm period over the length of the cylinder. A resistive divider network provides a uniformly graded potential that is maximum at the center of the TPC and decreases to ground potential at either end. The TPC is designed to operate with two different gas mixtures, P10 (10% methane in argon) and potentially at some point in the future 50% ethane in helium. Nitrogen gas between the gas vessel and the field cage provides the high voltage insulation for 30 kV, P10 gas operation. The third cylinder, or inner field cage, is a 1 meter diameter version of the outer field cage. A thin, electrically conductive central membrane joins the central electrodes of the inner and outer field cages. The nominal operating voltage is 30 kV at the central membrane, but it has been designed for a maximum operating voltage of 85 kV.

The field cage power supply is a Glassmann WS series 100 kV power supply with a custom EPICs/VME based controller with feedback control of the voltage using a drift velocity error signal. Some field cage system parameters:

Maximum voltage (power supply)	100 kV
Maximum current (power supply)	6 ma
Maximum stored energy (in power supply at 85 kV)	11 Joules
Voltage discharge time (power supply, no load)	< 15 sec
Maximum operating voltage (field cage with C_2F_6 insulator)	85 kV
Maximum operating voltage (field cage with N_2 insulator)	60 kV
Maximum stored energy (in field cage at 85 kV)	11 Joules
Maximum field cage resistor chain current (total at 85 kV)	0.93 ma
Voltage discharge time (field cage)	< 14 sec

The field cage controller system is equipped with two interlock connections which require contact closure to enable.

The annular space formed by the inner and outer field cages is capped at either wheel by an array of 24 wire chambers or "sectors". A sector includes a large printed circuit board, or "pad plane", bonded to an aluminum strong back. Fine parallel wires arranged in a set of three planes form a gating grid plus a multiwire proportional chamber (MWPC). The circuit board also forms part of the gas envelope that contains the working gas, either P-10 or a 50/50 helium/ethane mixture. The anode wires of the sector MWPC are biased at up to 1600 volts. However, the exterior exposed surface of the sector remains at ground potential as does the wheel on which it is mounted.

The TPC is suspended from the magnet end ring on four aluminum supports. The supports attach to the wheel at the three and nine o'clock positions. Insulation at the wheel to support interface provides electrical isolation. An electrical ground is established at the field cage power supply in the electronic rack.

The laser system in the STAR TPC provides ionized tracks in TPC drift volume for spatial calibration of the detector. The laser system uses two Nd-Yag, class 4 lasers that produce pulses with the following specifications:

Wave Length (nm)	Energy (mJ)	Pulse Width (ns)
1064	450	6-9
532	200	6-7
266	50	4-5

The maximum repetition frequency is 10 Hz. The lasers are mounted outside of the magnetic volume on the floor of the assembly hall or WAH. The UV beam is expanded to 2 cm diameter and conducted (with mirrors) to the end cap wheels and injected into the TPC gas volume from 6 points around the wheels. In normal operation the beams are fully enclosed in tubes. The beams penetrating the TPC gas volume are broken up into multiple thin beams with bundles of 1.5 mm mirrors. The nominal energy density of all the beams in the gas volume is 2 micro joules per mm^2.

2.2.2 Safety Analysis

2.2.2.1 Hazards

The following possible hazards may be present during operation and/or maintenance of the TPC.

Explosion or fire due to use of P10 gas.

Crushing hazard due to suspended weight of the TPC

Electrocution due to the high voltage present at the field cages and sectors.

Suffocation due to the lack of air in the volume enclosed by the field cages and wheel assemblies (Nominally a class 2A confined space, concurrence of BNL S&H Services Division (SHSD) on designation required).

Laser burns due to the use of a class IV laser for TPC calibration.

2.2.2.2 Safety Systems

Detection

Flammable gas detectors will be used in the gas room and under the TPC.

Flammable gas detectors will be used in the insulator gas exhaust.

Oxygen detectors will be used in the TPC drift gas and in the insulator gas.

Mitigation

Explosion/Fire

The air in the TPC will be displaced by purging with nitrogen gas. The nitrogen gas will then be displaced by the working gas, P-10. The gas purity will be checked after filling to assure that less than a fraction of a percent of oxygen remains. The primary purpose of this oxygen monitoring is to maintain the performance of the TPC. A secondary benefit of this monitoring is that any leak in the system that permits oxygen into the gas volume will be detected very early. The operation of the power supplies will be interlocked to the gas interlock system which requires that pressures, gas mixtures, oxygen levels and flammable gas levels are within correct limits.

A design parameter for the TPC was that the leak rate of detector gas not exceed 0.06 l/s. During construction of the TPC, each sector pad plane was helium leak tested (10 mTorr base pressure, < 10-8 std-Atm cc/min). This was followed by a gas (P10) sniffer leak test of each assembled sector. No detectable leakage was allowed.

Both a gas sniffer and a helium leak checker were used on the Outer Field Cage (OFC) during fabrication. All detectable leaks were repaired during the bonding of the inner skin of the OFC. The sensitivity of the sniffer was measured to be better than 5 cc/min with helium as the test gas. In addition, the outer field cage, being enclosed by an insulating gas, does not communicate directly with the atmosphere. Any gas that does leak through the outer field cage will be diluted by the inert insulating gas and should not present a significant hazard. The construction of the Inner Field Cage (IFC) will follow the same construction and testing methods as the OFC.

Gas leaking from the sectors or at the seal between the wheel and either the inner field cage or gas vessel will be diluted by forced air ventilation. Given the upper limit on the cumulative measured TPC gas leak rate of 3.5 l/min, a blower providing 35 l/min (1.25 CFM) will be sufficient to maintain the methane content in the P-10/air mixture to less than a quarter of its lower flammability limit of 4 %.

A flammable gas detector connected to a distributed network of sensors will continuously monitor the volume immediately outside of the TPC. This monitor will sound an alarm and shut off power to the TPC in the event that the ethane (or methane) level exceeds 25% of the lower flammability limit. Flammable gas detectors for the WAH are also included in the conventional facilities plan. The TPC will coordinate with STAR Conventional Facilities Group to tie operation of the TPC gas, high voltage and laser to these sensors.

The attached supply of flammable gas (methane) will not exceed 80 cubic meters at any one time. The gas, in the form of 12 cylinders attached to a common manifold, will be located in an outdoor weather shelter at least 2 meters from the closest structure. One half of the cylinders will be valved to the manifold at a time. Mixing of the flammable and inert gases will occur in a specially prepared Gas Mixing Room within the STAR Assembly Building (Assy. Bldg.). A description of the gas system and its operation is contained in STAR Note ST0268, “TPC Gas System Operation at BNL.”

Crushing

All supports and installation fixtures will be designed per STAR NOTE 105A, STAR Mechanical Design Standards and Guidelines, Rev. A. These guidelines include a minimum safety factor of 3 on yield stress for all structures and a safety factor of 5 if human injury would result from a failure. Design and testing of TPC lifting fixture was performed in accordance with the guidelines of LBL Health and Safety Manual, PUB 3000 Ch.5. IV and will be submitted for review in accordance with BNL ES&H Standards Ch. 1.6.0.V. Refer to LBL Engineering Note M7548 (STAR Note pending), “TPC Lifting Fixture.”

Electrocution

All high voltage supply lines will be coaxial with a grounded exterior conductor. The field cage supply line will be enclosed in metal conduit from the power supply to the detector’s magnet end ring. If possible flexible conduit will extend through the magnet pole gap to the feedthrough at the TPC end cap. The current rating of the field cage power supply will not exceed 4 mA, well below the 10 mA needed to cause a serious shock in humans. The over-current limit settings will typically be 1 to 2 mA.

The high voltage regions of the TPC and unshielded portions of the high voltage cable are within the TPC volume and are not normally accessible. However, should maintenance or repair require access to the interior of the TPC a manual grounding system, in conjunction with written procedures, will be used to assure that individuals are not exposed to high voltage. The voltage discharge rate is < 15 seconds after power to the field cage power supply is removed and access time to high voltage will require more than this time. Power loss to the EPICs/VME field cage voltage controller opens a relay removing AC power in the field cage power supply.

The field cage power supply will be fitted with a lockable plug cover and will be treated in accordance with the Lockout/Tagout provisions of OPM 5.1.5.1. Lockout/Tagout.

The maximum voltage required by the anode wires of the sector MWPC will not exceed 2 kV. All connectors will be SHV type which have a rating of 6 kV. The maximum rating of a MWPC power supply channel will be 5000 volts and 1 mA. The voltage limit will be set no higher than 2000 volts by a potentiometer located at the backplane of the rack mounted card. This voltage limit of 2000 V is only for equipment protection.

The sector's gating grid is biased at up to 300 vdc and driven from the bias potential by ±150 volt pulse. The gating grid power supply can produce 40 A peak and 0.020 A rms. The gating grid power will be treated in accordance with the applicable provisions of BNL ES&H Standard for Lockout/Tagout.

Suffocation

After operation and before maintenance of the TPC, the working gas will be purged with nitrogen to remove all but trace amounts of methane prior to ventilating with air. After purging, gas flow to the TPC will be blocked and locked out as will the power to the TPC. Access to the region between the field cages will be provided by removing one or more sectors from the wheel. The working volume of the TPC constitutes a confined space. ES&H Standard 2.2.4 will be followed including forced air ventilation and oxygen and flammable gas concentration measurements to assure that conditions are safe for entry. Written procedures will detail the precautions to be taken to prevent injury to personnel and/or equipment damage during work inside the detector. All personnel who do work inside the TPC will be required to read and follow these procedures.

Laser Burns

Under normal operating conditions all laser beams will be completely enclosed in metal or plastic enclosures that require either a screw driver or wrench to access. Only the 266 nm beam will enter the enclosed external laser beam lines. The other wavelengths will be contained within a commercial laser enclosure. The commercial laser system enclosure will be equipped with industry standard interlock systems. Normal tuning will be done by remote control with remote sensors. In this state of normal laser status people operating the laser must be trained in the use of the laser system, but formal laser safety training will not be required. The laser will be interlocked to prevent operation if flammable conditions exist in the TPC since the laser may be a potential ignition source. Laser systems will be designed and operated in accordance with the laser requirements specified in BNL ES&H Standard 2.3.1 and RHIC OPM 5.2.3.1 Lasers, in conjunction with review by the BNL Laser Safety Officer.

For initial installation and occasional maintenance operations the laser beam line and laser housing will be opened for coarse alignment. Under these conditions the screens will be placed around the working region of the TPC. Laser in use indicator lights will be placed at the access points to the screen. UV protective goggles will be worn by workers with access to this controlled area. These workers will be required to have laser safety training. When the beam enclosures are open and the laser system is not in use the standard commercial interlock key on the laser will be removed.

Routine laser maintenance will be done by qualified trained personnel.

An operation and safety procedure document will be written for the laser system. The Laser system will be operated in accordance with RHIC OPM 5.2.3.1 and with approved controls for setup and alignment operations.

<u>Administrative Controls</u>

Administrative controls in the form of check lists and operating procedures will be used in start up and monitoring of the gas system.

Lockout tagout procedures will be used when the TPC or connections are open to exposure for the gated grid driver or the field cage high voltage.

Operating procedures will be followed during installation and alignment of the laser system.

2.2.3 Modes of Operation

The normal operation mode will have all the systems running.

Other modes of operation include operating each subsystem independently with the rest of the systems turned off, i.e.: gas system, laser system, gating grid system, field cage high voltage and anode wire voltage system. When these systems are operated without the gas system turned on operational procedures will be followed to insure that the TPC is properly secured with either air, argon or nitrogen in the TPC volume. Operation of the field cage high voltage will be limited in voltage according to hold off limits for the gas that is currently in the TPC.

There will be cosmic ray mode of operation in the assembly hall and the WAH. These modes may require separate connection methods for water, gas and power.

2.2.4 Assembly and Maintenance

Assembly involves transfer of the TPC from the transportation frame to the insertion frame.

There will also be jobs that will require working inside the TPC to correct field covers on some of the laser optics. This will require use of scaffolds with spring boards to work inside the field cage volume. Official procedures for entering a confined space will be followed. The work will also require removal of sectors which will need a crane to manipulate the sector insertion tool.

Inserting the TPC into the magnet will be done with side rail structures and defined procedures.

2.2.5 Emergency Procedures

Procedures will be drawn up for dealing with fire, and gas and water leaks. In case of fire, power to the experimental area will be turned off. This will put the gas system into automatic purge mode. In case of gas leaks such as a ruptured P10 line or inner field cage hole power will be turned off removing ignition sources and putting the gas system into auto purge mode. The room lights should be left on so that corrective action is easier to carry out. For instance holes can be closed with duct tape. This would be particularly beneficial if the leak is in the exhaust line because this will prevent dumping of the full TPC volume of P10 into the room. In case of water leaks in the cooling water on the TPC, high voltage will be turned off, the circulating pump will be shut off and efforts will be made to prevent water from contaminating the back side connector surfaces on the sectors.

2.2.6 Maintenance

Electronic rack filters will be changed on a scheduled basis. Purifier canisters in the gas system will run through an activation cycle when they loose efficiency. Interlocks and sensors on the gas system will be checked according to a prescribed procedure and schedule. Sectors will be replaced with spares and repaired as needed.

2.2.7 Training and Qualifications

When the gas system is in normal operation mode there will always be a primary gas system operator who is responsible. Gas system operators who have passed the training requirements will be identified in the gas system log book as well as future training data bases that are instituted for operations of this nature. In the future additional gas operator trainers will be identified. Only these trained operators will be allowed to start and operate the gas system. Operators and other people changing gas bottles on the gas system will be required to take the BNL compressed gas training.

A similar scheme of local expert training will be used for operation of the field cage high voltage system and the anode wire voltage supplies. Operation of these two systems, however, are much simpler but training is still required to avoid potential equipment damage. LOTO training will be required for people securing the field cage high voltage system for work inside the field cage or for securing the gating grid supply.

BNL laser training will be required for anyone operating the laser system with the beam covers removed. The covers will only be removed for coarse alignment of the laser beam. Fine tuning can be accomplished with the beams completely contained and can be done by people who have not had BNL laser training. In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.3 Time-of-Flight Detector (TOF)

Possible future upgrade (no write-up included).

2.4 Solenoidal Magnet

2.4.1 Overview

The STAR magnet is a large solenoid which will produce a magnetic field of up to 0.5 Tesla over the TPC volume. The dimensions of the magnet are 5.24m ID, and 6.2m long. The coils are made of Aluminum. The requirements for the magnet are:

To have a solenoidal field that is known/measured to better than one part in a thousand. The maximum distortion in the position of the drifting electrons must be correctable to 500 μm or less.

To accommodate the EMCAL inside the coils, with short paths for fibers to phototubes outside the iron.

To be constructed in the assembly hall and rolled into place.

Pole tips roll back "in-situ" for minor service to detectors.

Roll back to assembly hall for major repairs.

The subsystem consists of the magnet, five power supplies to supply current to the magnet, PLC based controls and monitoring, a bus system to bring the power to the coils, and hydraulic based moving systems for the main magnet and the two pole tips.

Most of the amp-turns are supplied by the main coil packages, and the space trim and pole tip coils correct for end effects. The back legs consist of 30 steel bars with gaps in between. Fibers from the EMCAL are brought out in between coil packages and through the gaps between back legs.

The magnet moves via Hillman rollers which ride on carefully aligned steel plates. The pole tips have special carriages which ride on other rails. The weight of the magnet is approximately 1200 tons.

One should note that the space trim coils are expected to run at about 10% higher current than the main coils; this is achieved by the use of two booster supplies. The total DC power, based on the predictions of POISSON is 3.4MW. The power supplies are located on the second floor at the East end of the Assembly Building. A combination of solid and water cooled Cu buses bring the power to the magnet, in either the Assembly Building or the Experimental Hall.

The magnet is cooled by low conductivity water at 1072 gpm with a pressure drop of 120 psi and a temperature rise of 20 deg F.

2.4.2 Safety Analysis

2.4.2.1 Hazards

a. AC Power

The power supplies run off standard AC power. The main supply uses 13.8KV three phase, while the four smaller supplies use 480V three phase. These voltages are potentially hazardous.

b. Magnet Power Supplies

The power supplies contain potentially hazardous AC and DC voltages. The power levels are high.

c. Magnetic Fields

The DOE order 5480.4 places limits on personnel exposure to magnetic fields, namely .06 Tesla whole body or 0.6 Tesla to the extremities on a daily time-weighted average basis.

Workers with implanted cardiac pacemakers should not be exposed above 0.001 Tesla. Ferrous objects should be prohibited, or must be used in a fashion which prevents them from being a hazard.

d. Leads from Power Supplies to Magnets

The leads carry currents as high as 5330 amps, at voltages as high as 350 Volts.

e. Motion of Magnet and Pole Tips

There are two potential hazards associated with moving all or part of the magnet. The magnet as a whole is being built in the Assembly Building. and will be moved on rails into the Wide Angle Hall (WAH). It is expected that for major upgrades the magnet will be moved back to the assembly hall. The two pole tips can also be removed to allow access to the detector elements; this can occur in the WAH or in the Assembly Building.

f. The magnet must be protected against high temperatures and electrical short circuits. The magnet is designed to operate at full power at an average temperature of 85 deg F. This is achieved by regulating the input water temperature. Should a blockage occur in a single water path, this must be detected, and appropriate action taken. The magnet has been designed to avoid electrical shorts; however, because of the potential loss of time to the experiment, great care must be taken to detect a turn to turn short as early as possible. For example, if a turn to turn short occurs within a pancake(the most probable failure mode) early detection would allow continued running with a booster supply putting twice the current through one of the two shorted coils in a pancake. If a short is not detected quickly more extensive damage to the coils is likely and temporary solutions will probably not be available.

g. Cooling Water Leaks

Leaks in the cooling water system could lead to damage to the coils and to the nearby electronics.

2.4.2.2 Safety Systems

Detection

<u>AC Power</u>

Circuit beakers will be used to trip on overcurrent.

<u>Magnet Power Supplies</u>

The following items will be monitored when the power supplies are in operation:

Water flow and differential pressure switches

AC over voltages and currents

Phase imbalance, loss of phase, phase rotation, DC ripple

Over temperatures

Fuse monitoring system

Water flow

Ground fault

The cabinets will be controlled with an accountable key lock (Kirk Key).

Magnetic Fields

Flashing lights will be used to warn that the magnet is on. Before energizing the magnet in the Assembly Building., or after access when it is in the WAH procedures will include a sweep of the area before turning on the magnet. Crash buttons will be located in strategic locations to allow fast turn off of the magnet in an emergency.

Motion of Magnet and Pole Tips

Standard procedures, barriers, and lockouts will be used to ensure safe operations.

High Temperatures and Electrical Short Circuits

A PLC based detection system will be used. Every water path in the coils and the bus work will be equipped with a thermistor to measure the output temperature and a Klixon temperature switch as a final backup. The voltage drop will be measured across every conductor in the magnet.

Cooling Water Leaks

Water leaks will be detected by a combination of water mats and tracetek leak detection/location system. The system is designed to detect leaks in the hoses and fittings.

Mitigation

AC Power

All power wiring, from the 13.8KV source to power supplies, the circulating water system, and all other loads at all voltages is in accordance with NEC, Industry and BNL Electrical standards. All electrical equipment is "Dead Front" construction and is grounded to meet the standards.

Magnet Power Supplies

Many steps have been taken to ensure safe operation:

(i) Transformers

All transformers were designed to ANSI/IEE, NEC and NEMA standards.

All undergo standard testing.

Outdoor units undergo BIL Testing.

Outdoor units use silicone insulating liquid.

The outdoor units have the following safety systems:

Pressure relief diaphragm

The ability to withstand an internal vacuum of 1 torr without deforming

Alarming fluid level gauges

Alarming fluid temperature monitor

Pressure-vacuum gauges

(ii) Rectifier Modules

All rectifiers are designed to ANSI/IEEE, NEC, and NEMA standards.

All cabinets are compartmentalized with an accountable key lock (Kirk Key).

All voltages greater than 10VAC and 50VDC are barriered.

All undergo standard testing.

All undergo potential testing.

There is a fail-safe control system. Trips will occur for the following faults:

Blown current limiting fuses

Water flow and differential pressure switches

AC over voltages and currents

Phase imbalance, loss of phase, phase rotation, DC ripple

Over-temperatures

Fuse monitoring system

Water flow

Ground fault

Magnetic Fields

Barriers will be set up to ensure that the above hazards are avoided. The main fringe field from the magnet is in the region of the holes in the pole tips. It is very difficult to predict the field outside the return yoke, but based on experience with other large magnets it is expected to be <0.04 Tesla near the iron and falling off rapidly with distance.

The magnet will be mapped in the Assembly Building. Before measurements of the fringe fields have been made the barriers will be set conservatively to avoid the Hazards described in C (1). Warning notices will be placed at every entrance to avoid problems with pacemakers. In addition it is possible that the field in the rooms immediately to the West will also require warning signs.

During normal operation when the magnet is in the WAH the power supplies will be locked off during "controlled and "supervised" periods except for very short access ;if it is necessary to run the magnet with the hall open the barriers will alleviate the hazard. In all cases, "Supervised Access Procedures" will be developed to warn about the magnetic field Hazards and to specify that entry inside the barriers will need special permission.

Leads from Power Supplies to Magnets

The leads will protected in the following ways:

All conductors will be:

Insulated or barbered with tools needed for removal or enclosed by an accountable key lock (Kirk Key) controlled barriers (or barriers conforming to BNL ES&H Manual 1.5.3.)

All barriers will have appropriate signs.

There will be required documented site specific training for all personnel working on the system.

Motion of Magnet and Pole Tips

Procedures will be developed to ensure that all necessary disconnects will be made before the magnet is moved. During the actual moving barriers will be established to keep people away from the moving elements. Seismic tie downs have been built for the whole magnet and for the two pole tips in both the Wide Angle Hall and the Assembly Building.. It is projected that any move can be completed in an 8 hour shift; should that not be the case the crews will continue the process until it is completed. Accountable key locks (Kirk Key) will be used to ensure that the power supplies cannot be activated when the magnet is disconnected.

High Temperatures and Electrical Short Circuits

A PLC system with temperature, voltage and moisture detectors will be used to detect abnormal performance. During the setup and testing of the magnet the actual set levels will be determined so that safe operations will be ensured without excessive spurious warnings or trips. Three actions are then available, listed below in order of increasing severity of the problem.

(i) A warning will be issued to the operator if unusual temperatures or voltages are detected.

(ii) A slow (minutes) turn off of the magnet can be initiated by the PLC.

(iii) An immediate trip can be initiated by the PLC or by a "normally closed" serial string of

Klixon temperature-trip devices at the output end of each water path in the coils and leads.

Cooling Water Leaks

The magnet will be shut down if a leak is detected, followed by shutdown of the water system.

Administrative Controls

AC Power

All work on the AC connections will be performed by authorized electricians.

Magnet Power Supplies

All work on the power supplies will be performed by authorized technicians from the power supply group. In addition there will be warning signs at the entrance to the power supply room to limit access.

Magnetic Fields

Barriers and warning signs will be used to keep people out of the hazardous area. Training will be used to warn about the hazards listed above. Entry inside the barriers will require special permission.

Leads from Power Supplies to Magnets

Barriers and warning signs will be used , as described above.

Motion of Magnet and Pole Tips

Procedures and check off lists will be developed to prevent hazards while the magnet or pole tips are being moved.

High Temperatures and Electrical Short Circuits

It will be required that a trained operator be present whenever the magnet is energized. RHIC rules indicate that at least two people be present as a safety precaution.

2.4.3 Modes of Operation

The magnet will be run at 5kG or 2.5kG central field.

2.4.4 Emergency Procedures

In addition to the systems described above the magnet can be turned off via well-labeled crash buttons both inside and outside the WAH. Connections will be established for emergency shut off from other parts of the STAR interlock system. It is vital that any system capable of "crashing" the magnet be extremely reliable.

2.4.5 Maintenance

Routine maintenance of the rectifier assemblies will take place each year. This involves testing interlocks, cleaning of filters and checking the regulation of the units. The transformers and swift gear will require routine maintenance by the line crew. The breaker must be tested yearly, the relays calibrated and the transformers and insulator must be inspected, cleaned and tested; the transformer insulating fluid must be tested for electrical integrity and devolved gases.

2.4.6 Training and Qualifications

Whenever excitation of the magnet is possible, everyone with access to the area must have received training on procedures to be followed in the presence of the magnetic field. When the magnet is in the WAH this will be handled as part of the general procedures. However, the magnet will be tested and measured in the Assembly Building, almost a year before the move into the Hall, so special training and procedures will be invoked for this situation.

In accordance with procedures, the area near the magnet will be cleared before it is turned on. Whenever the magnet is on a trained operator must be present to react to alarms. Special training, including detailed check lists, will be provided. Movement of the magnet or the pole tips will be done only by trained personnel, with procedures and check lists.

In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.5 Electromagnetic Calorimeter (EMC)

2.5.1 Overview

The STAR electromagnetic calorimeter (EMC) is designed to analyze photons, electrons and hadrons. The EMC is a lead-scintillator sampling calorimeter. The main mechanical components of the EMC will be located inside the solenoid magnet coils and the iron flux return. The inner radius is 2.20 meters and the length is 6.87 meters. It consists of 120 wedge shaped modules, each of which is 6 degrees in Φ and 3.43 meters in length. Each module is sub-divided into 40 projective towers. Each tower has 20 layers of lead and 21 layers of scintillator giving a total of 100,800 scintillator tiles of varying shapes. The total weight of the scintillator tiles is about 12 tons. Each scintillator tile is connected to a wavelength shifting optical fiber that will go to Melz FEU115M PhotoMultiplier Tubes (PMTs). All the fibers from the 21 tiles in each tower will go to a single PMT, of which there will be a total of 4800. The first two scintillator tiles in each tower will be read out by an additional fiber that will be connected to multi-anode PMT's at a later date, as an upgrade, provided funding becomes available.

The EMC will also include a Shower Maximum Detector (SMD) with a high granularity to increase the two photon resolution of the EMC. The shower max detector in principle is similar in design to those used in the Collider Detector Facility (CDF) at FNAL. It consists of a double-sided wire proportional chamber and strip planes. The chamber will be filled with an Ar - CO2 (5-10 %) mixture at STP. The shower maximum detector will be biased up to 1.6 kV. The Preamplifier/Shaper Electronics cards will be placed at the 0 =1 end of each EMC module. Each of these two cards will contain 150 channels of the strip readout electronics. The total power dissipation in the volume of the preamplifiers will be approximately 30 W. The low voltage power supply for the preamplifiers will be +/- 6 V.

2.5.2 Safety Analysis

2.5.2.1 Hazards

<u>Mechanical Hazards</u>

After assembly the EMC is mechanically a static structure posing no mechanical hazards. Hazards do potentially exist, however, in the 150 ton mechanical system during abnormal conditions such as seismic activity. The EMC mechanical sub-system has been designed to withstand accelerations of 0.25g in all directions, in addition to gravitational loading, to protect against such eventualities.

Mechanical hazards do exist during the assembly and maintenance of the EMC, and these are discussed in section 2.5.3.

<u>Electrical Hazards</u>

The full barrel EMC utilizes 4800 single channel FEU115 PMTs. These are biased by Cockroft Walton active bases. The total estimated power dissipation of each base is estimated to be

100-150 mW. The input to each tube base will be 12-24 volt DC. The PMTs are each encased in a concentric mu-metal and soft iron magnetic shield. These shields will be grounded to the magnet backlegs via the support structure. Additionally a ground will be supplied via the DC input power line.

The Cockroft Walton bases are low power devices, and their dissipated power is mostly due to the current drawn by the leakage of the diodes and capacitors used in the multiplication chain, and the actual current drawn by the PMT dynode structure. As such the overall heat generated in the base is very small. Furthermore the materials used in the construction of the bases are chosen according to specifications of BNL Environmental, Safety, and Health Standard section 1.5.2. The CW PMT base will have, in addition to built in active current limiting, passive current limiting (e.g., fuse or termistors).

The PMTs and bases will be enclosed in light-tight boxes mounted outside of the magnet return iron yoke. The PMT boxes will be electrically grounded through their mechanical supports to the magnet iron. A second back-up ground will also be provided. Since the PMT bias voltage is confined to the PMT tube base, and the base and PMT are enclosed in a grounded box (e.g. a fire retarding composite light material with grounded conductive shielding), the electrical hazard is safely shielded from personnel exposure. These boxes will be cooled internally with a water chilled heat exchanger and electrical fans. The temperature inside the box shall be monitored through the slow controls at a few places along the length of the box.

The EMC Front end electronics (FEE) will be mounted in 30 crates, which will reside on the iron flux return bars of the STAR magnet. The power to these crates will be supplied as 120 V AC. Each crate will contain 6 printed circuit (PC) electronics cards. Each of the cards will dissipate less than 70 W of power for a total power dissipation in the crate of less than 450 W. This power will be drawn from the crates and dissipated into the room air via electrical fans.

The EMC conventional systems consist of the 120 V AC power, the associated power transmission lines, and the cooling systems for the FEE crates and the PMT boxes. Approximately 13 kW of power will be supplied to the 30 FEE crates as 120 V AC power. In addition approximately 50-100 amps of 24 V DC (DC power generated in the FEE crates) will be used by the PMT, LED, the PMT light tight box cooling systems, and the SMD gas system. The distribution of this power will follow guidelines laid out in NFPA-70 (NEC), and will be fused by separate paths to limit current to ampacity. All personnel involved in the installation and operation of the EMC will receive training in the use of electrical systems as required by the BNL ES&H Manual and RHIC OPM. All power supplies installed on the racks will be isolated from local ground (float with respect to the detector ground). The current and voltage levels of all DC power supplies will be monitored via EMC controls.

The DC power supplied by the power supplies will be distributed via bus based metallic distribution boxes. The bus system will adhere to the guidelines laid out in NFPA-70 (NEC). The hazards associated with power distribution will be abated by a lock-out tag-out (LOTO) procedure, mechanical barriers, electrical interlocks, and proper training of all personnel involved.

The PMT light tight boxes will be cooled internally by a water chilled cooler system. In addition, since the internal box temperature is monitored at several places along the length, a consistent change in the box temperature may indicate a problem with the chiller system (the fan system includes redundancies and therefore is much less likely to be the cause of a temperature rise).

All of the Shower Max systems will be enclosed inside the grounded metal box forming the environmental and light tight enclosure of the EMC module. The high voltage part of the power distribution system will have additional covering, so the electrical hazard is safely shielded from personnel exposure. Both the high voltage and low voltage power supplies will be fused by separate paths to limit current to ampacity. The wire/strip Shower Max. chambers will be biased up to 2 kV and would draw less than one mA with a trip set point of one mA during the first few minutes of each beam storage in RHIC. Six HV power supplies, along with fanout boxes, will be used to distribute the anode wire HV to all SMD chambers. Requirements for HV systems are stated in RHIC OPM 5.1.5.0.1 of the RHIC Project OPM and BNL ES&H Manual, and will be applied without exception to the SMD high voltage power systems used in the STAR EMC. All personnel involved in the installation and operation of the SMD will receive training in the use of electrical systems as required by the RHIC Project.

The two SMD preamplifier/shaper cards at the $\eta=1$ end of each EMC will contain 150 channels of the strip readout electronics per card. The total power dissipation in the volume of the preamplifiers will be approximately 30 W. The low voltage power supply for the preamplifiers will be ± 6 V, and will come from one of the four SMD readout crates mounted on each end of the STAR detector. The power to the SMD readout crates will be supplied as 120 V AC. The total power dissipated in each of the 8 SMD readout crates will be less than 500 W.

The SMD conventional systems consist of the 120 V AC power, the DC power transmission lines from the SMD readout crates to the SMD FEE, the SMD anode wire HV system, and the SMD gas system.

Material Hazards

The main materials which comprise the EMC are: lead, plastic scintillator, aluminum, and steel. Of these, only lead presents a significant hazard. The lead used takes the form of sheets, alloyed with 1% Antimony for stiffness. All lead sheets are encapsulated within an aluminum and stainless steel environmental and light tight enclosure at the assembly sites prior to being shipped to BNL.

Radiation Hazards

The STAR Barrel EMC will not contain a radioactive calibration system that is resident on the detector. For calibration and testing purposes, two stainless steel tubes are embedded into a thin sheet of G-10 and run the length of each EMC module. A radioactive source may be inserted into these narrow tubes (~ 1 mm dia.) for testing with the EMC module located either in a remote test stand or mounted in the STAR detector.

Operating personnel will receive appropriate training as required by in the BNL Radiological Control Manual concerning the use and handling of the radioactive material. The radiation environment will be surveyed and ALARA practices strictly adhered to and enforced. All workers will be made aware of the necessity to maintain stringent control of radioactive materials.

Pressure Vessel Hazards

The SMD gas system consists of a high purity Ar/CO2 premixed gas manifold system and a nitrogen purge gas system. Both of these systems consist of automatic changeover, high purity, and continuous manifold systems with a maximum inlet pressure of 3000 psi. Multistage regulators will reduce this pressure down to 2-10 psi for delivery to the SMD modules. At any given time one of these gasses can be used in the SMD. While the two gasses used in the SMD are non-flammable and non-hazardous they are delivered in high-pressure vessels/cylinders and therefore are a potential safety hazard. As such all the components of the gas inlet manifold system will comply with the requirements of the BNL ES&H Manual (sec. 1.4.0 and 1.4.1).

All high-pressure lines will be equipped with pressure relief valves. The pressure in the gas manifolds on both the high pressure and low pressure sides of the regulators will be readout via pressure transducers, and monitored via slow controls. In addition the flow and pressure are also monitored in the main 2 inch gas line and flow may be adjusted via the slow controls.

The distribution of gas to the SMD modules is provided via two manifolds located at the two ends of the detector. Each manifold consists of 30 small distribution systems, which are electronically controlled via the EMC slow controls. These distribution boxes are daisy chained via 1 inch flexible Teflon hoses with stainless steel shielding. The distribution boxes (these are actually open boxes) are metallic and contain electronic PC boards to drive the solenoid gas valves, which control the flow of the gas into the SMD modules. These valves are used to adjust the flow rates for the higher flow rates required during the initial flushing of the system with the nitrogen gas, and to reduce the flow down to the nominal value during the normal operation of the system. The total electrical power dissipation in each valve is less than 1 watt. The power requirement is 30 mA at 24 V. Therefore, the dissipated heat load can be easily taken care of by convection cooling. Due to the low power dissipation of each distribution box we do not expect any hazards associated with heat or electrical issues. All the electronics design shall adhere to OPM 5.1.5.1.

The pressure in the inlet of these boxes is 2-10 psi and in the outlet is slightly higher than atmospheric pressure. Flexible, fire retardant tubing will be used to carry the gas from the distribution manifold to the SMD module, and return the exhaust gas to a bubbler. The bubbler will be monitored with an electronic system (e.g., a video system or a photoelectric cell). This will allow one to detect low flow rates in leaky chambers. The gas will be vented to the atmosphere. Since the total flow rate is less than 5 lpm the ventilation system of the hall should be able to easily handle purging of this gas.

Magnetic Hazards

The close proximity of the EMC phototube boxes to the solenoid magnet power connections and magnet cooling water hoses raises some additional safety issues. In addition the large magnetic fields could present a substantial personnel hazard if the magnet were energized during EMC maintenance work. These hazards will be abated by a lock-out tag-out (LOTO) procedure, mechanical barriers, electrical interlocks and proper training of all personnel involved.

Fire Hazards

The most obvious fire safety issue is the large amount (~12 tons) of combustible fuel present in the polymer scintillator. This fire hazard is minimized by the isolation of the tiles in stainless steel and aluminum light-tight boxes, and by their separation by lead plates. The degree of isolation limits the access of oxygen to support combustion and requires an enormous amount of heat to raise the temperature of the scintillator material to the ignition point. For example, polyvinyltoluene, a typical plastic used for scintillators, is stable up to 300 C. The amount of heat required to raise 150 tons of what is primarily lead to this temperature is enormous, approximately 5 giga Joules ($5x10^9$ J). No credible energy source exists in the EMC to generate such amounts of heat. It is also unlikely that a failure in the adjacent solenoid would generate sufficient amounts of heat to pose a combustion hazard for the EMC. As discussed in the section of the STAR safety document on the solenoid magnet, systems will exist to detect failures (i.e. cooling or direct electrical shorts) and shut the magnet down in a controlled fashion to eliminate the risk that the solenoid could generate sufficient heat to damage the EMC.

The shower max chambers will be operated with a non-flammable Ar/CO2 gas mixture and hence will not contribute any significant fire hazard. The shower max chambers themselves do not contain any flammable components. It is possible that the leakage of gases from the TPC could collect in the area where the EMC is located and present a flammable gas hazard. The hazard can be reduced to an acceptable level by sensors to detect the build up of such gases and allow the operators to shut down the flow of flammable gas to the TPC, to purge the flammable gas from the TPC and shutdown electrical power to STAR.

Some of the EMC electrical systems present a level of fire risk. This hazard will be mitigated by strict adherence to the provisions of NFPA-70 (NEC) and the presence of sensors designed to detect combustion and trigger the shutdown of electrical power and fire suppression systems, or warn the operators that a problem exists.

2.5.2.2 Safety Systems

Detection

<u>Electrical Safety Systems</u>

The PMTs and bases will be enclosed in light-tight boxes mounted on the outside of the magnet return iron yoke. The PMT boxes will be electrically grounded through their mechanical supports to the magnet iron. A second back-up ground will also be provided. Since the PMT bias voltage is confined to the PMT tube base, and the base and PMT are enclosed in a grounded box (e.g. a fire retarding composite light material with grounded conductive shielding), the electrical hazard is safely shielded from personnel exposure. These boxes will be cooled internally with a water chilled heat exchanger and electrical fans. The temperature inside the box shall be monitored through the slow controls system at a few places along the length of the box.

The EMC slow controls is a VME/EPICS based system. Its primary function is to control and monitor the functions of various sub systems, and in cases of fault, notify the operators. As such this system is required to interface not only to the EMC sub systems requiring monitoring and control, it will be interfaced to the STAR experiment controls for detector initialization and run controls. It will adhere to the standards set forth by the slow controls group's requirements document as well as to the OPM 5.1.5.1. The EMC control is expected to occupy two 9U standard STAR VME crates. Several different commercially available VME I/O modules will be used to monitor and control different EMC sub systems. Of these the HDLC link with the Radstone interface module will be used (same system as the TPC FEE and the CTB) to program the EMC FEE. The remaining modules will be used to monitor Analog as well as digital signals from various subsystems. Because of the possible potential difference between the detector ground and the crate ground large currents may flow in the low impedance signal lines connecting the detector based electronics to the control modules; therefore it is essential to use isolated signal paths. All digital and analog cables shall be twisted pair differential or shielded coaxial to minimize ground loop and EMI problems. One potential problem in any control application is the possibility of positive feedback in the control loop, which could result in unpredictable behavior of the system being controlled. Systems with multiple overlapping feedback loops are particularly susceptible to these kind of problems. Every effort will be made to avoid such control loop problems and in cases where such loops are necessary additional monitoring systems will be implemented. All control I/O modules shall meet the National Electrical Code specs. The current and voltages of the power supplies on the VME crates will be monitored.

2.5.3 Assembly and Maintenance

Since the EMC has an overall weight of 150 tons (distributed in the 120 EMC modules) for the barrel and 30 tons for each end cap, there are intrinsic safety questions concerning system integration and the movement of heavy articles during assembly or disassembly. The EMC support hardware, which couples the EMC to the STAR solenoid magnet and iron return yoke, is broken up into 270 pieces each weighing up to 50 lb. and will be installed by hand. After the installation of the primary attachment supports, 120 rails, weighing a few hundred lbs. each, will be installed using a lifting fixture on the inside surface of the STAR magnet.

Each calorimeter module will weigh about a ton. To install them, a lifting fixture that can be attached to the installed rails and bolted to the face of the magnet on one end, and supported by the building crane on the other, will be used. The one ton calorimeter modules will be installed on rails on the lifting fixture. The fixture will then be positioned with the crane and have one end bolted onto the magnet face. An additional connection to the crane, a come-along, will permit fine adjustments of the position. The modules will then slide from the fixture rails onto the permanent rails. This basis approach of using a fixture with holes over the center of gravity for each angle, and the second attachment for fine adjustment, was used successfully in the construction of the STAR magnet.

The EMC electronics will be mounted outside of the magnet iron and some of the boxes containing PMTs will be as much as 27 ft above the floor. These boxes will have to be accessed during detector commissioning. Height may also be a problem on the end cap electronics since there are no readily available electronics platform floors near-by. Man lifts or cherry pickers may have to be used.

2.5.4 Training

In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.6 Forward Time Projection Chamber (FTPC)

2.6.1 Overview

The FTPC provides tracking of charged particles from heavy ion collisions at RHIC. Measurement of track curvature in the magnetic field provides charge and momentum determination.

There are two chambers, one at each side of the collision point. They will be positioned at $|z|$ = 150 to 270 cm. The basic structure of each FTPC is a cylindrical aluminium frame of 120 cm length and 72.8 cm diameter with 30 openings for the readout sectors.

The mechanical and electrical parameters are listed in table below.

The chamber is supported and positioned by 4 aluminium bars connected to the inner field cage ring at the central TPC. A finite element analysis of the complete chamber, including the weight of the readout chambers, electronics, cables etc., gives a vertical deformation by gravitation of less than 300μm. The radial field is established by a tube around the beam pipe, at negative high voltage, and the readout chambers at ground potential on the outer wall of the cylinder. At the ends, the radial field is defined by a plane of 17 concentric toroidal potential rings, made out of Al tubes with 300μm wall thickness, and a corresponding resistor divider chain. The cylinder is closed with 2×100 μm thick Mylar foils at both ends. The FTPC is designed to operate with a nonflammable gas mixture at a flow of 0.3 l/min during normal operation and 1.5 l/min during purging.

The chamber will be operated with a nonflammable gas mixture of 50% Argon and 50% Carbon Dioxide. There will be two batteries of gas bottles outside the building in the storage area (Ar 200 bar, CO_2 70 bar). The pressure reducer is on the batteries and the gas tubes inside the building have only a pressure of 2 bar (or 30 psi).

FTPC	
inner radius outer radius weight	7.4 cm 36.4cm 180kg
Cylindrical field cage and gas	containment
inner radius outer radius volume weight	8cm 30.5cm 340 liter 55kg
Gas	
gas mixture cumulative leak rate over-pressure	Ar 50% - Co_2 50% < 0.15 l/m max. 5 mbar
Electric field	
cathode voltage loading resistors current capacitance stored energy	max. 20kV 150 MΩ 0.13 mA 50 pF 8mJ
Readout sector	
# of sectors HV on sense wires	30 max. 2kV

Inside the building, in the gas mixing room, we have a mixing system with 2 mass-flow regulators and a special mixer tube. Downstream of the mixer tube the transfer lines go into the experimental area to the FTPCs. From the outlet of the chambers transfer lines will bring the gas back to the mixing room where O_2 and water detectors are located. After that the gas exhausts outside the building.

2.6.2 Safety Analysis

2.6.2.1 Hazards

The following possible hazards may be present during operation and/or maintenance of the FTPC:

- Crushing hazard due to suspended weight of the FTPCs..
- Electrocution due to HV present at the field cages and the readout chambers.

- Laser burns due to the use of a class IV laser for calibration and test purposes.
- Oxygen deficiancy hazard (ODH) is negligible due the small volume of the FTPCs.

Note: There is NO flammable gas hazard due to the Ar/CO_2 mixture, which is non-flammable and non-toxic.

2.6.2.2 Hazard Mitigation

The identified hazards will be mitigated by the following measures:

Crushing

All supports and installation fixtures are designed in accordance with STAR Mechanical Design Standards and Guidelines. These guidelines include a minimum safety factor of 3 on yield stress for all structures and a safety factor of 5 if human injuries would result from a failure. The transport and installation fixtures will be tested in accordance with OPM 10.6. The total weight is approx. 300 kg; 180 kg for the detector and $\geq$100 kg for the handling fixture.

Electrocution

All high voltage supply lines will be coaxial with a grounded exterior conductor. The current rating of the field cage power supply will not exceed 3 mA, well below the 10 mA needed to cause serious shock in humans. The over-current limit settings will typically be 0.5 mA. The connectors for the 2 field cage cables are LEMO (Type FFR.3y.425.CFAE 10G) which have a rating of 30 kV.

The high voltage regions of the FTPC are within the FTPC volume and are not normally accessible. However, should maintenance or repair require access to the interior of the FTPC, a manual grounding system, in conjunction with written procedures, will be used to assure that individuals are not exposed to high voltage. The voltage drops to a safe value within a few seconds after power to the field cage power supply is removed and access time to the interior of the FTPC will require more than this time. Power loss to the EPICs/VME field cage voltage controller opens a relay removing AC power in the field cage power supply.

The maximum voltage required by the anode wires of the readout chambers (MWPC) will not exceed 2 kV. All connectors will be SHV type which have a rating of 6 kV.

The sector's gating grid is biased at up to 300 vdc and driven from the bias potential by ±150 volt pulse. The gating grid power supply can produce a 40 A peak and 0.020 A rms. The gating grid power will be treated in accordance with the applicable provisions of BNL ES&H Standard for Lockout/Tagout.

Laser Burns

During normal operations the laser beams will be confined to enclosures that require either a screw driver or wrench to access. Only the 266 nm beam will enter the enclosed external laser beam lines. The other wavelengths will be contained within a commercial laser enclosure. The commercial laser system enclosure will be equipped with industry standard interlock systems. Normal tuning will be done by remote control with remote sensors. In this state of normal laser status people operating the laser must be trained in the use of the laser system, but formal laser safety training will not be required.

For initial installation and occasional maintenance operations the laser beam line and laser housing will be opened for coarse alignment. Under these conditions the screens will be placed around the working region of the FTPC. Laser in use indicator lights will be placed at the access points to the screen. UV protective goggles will be worn by workers with access to this controlled area. These workers will be required to have laser safety training. When the beam enclosures are open and the laser system is not in use, the standard commercial interlock key on the laser will be removed. Laser systems will be designed and operated in accordance with the laser requirements specified in BNL ES&H Standard 2.3.1 and RHIC OPM 5.2.3.1 Lasers, in conjunction with review by the BNL Laser Safety Officer.

Routine laser maintenance will be done by qualified trained personnel.

An operation and safety procedure document will be written for the laser system. The laser system will be operated in accordance with OPM 5.2.3.1 and with approved controls for setup and alignment operations.

2.6.2.3 Administrative Controls

Administrative controls in the form of check lists and operating procedures will be used to start and monitor the gas system.

Lockout tagout procedures will be used when the FTPC or connections are open to exposure for the gated grid or the field cage high voltage.

Operating procedures will be followed during installation and alignment of the laser system.

2.6.3 Modes of Operation

The normal operation mode will have all the systems running.

Other modes of operation include operating each subsystem independently with the rest of the systems turned off, i.e.; gas system, laser system, gating grid system, field cage high voltage and anode wire voltage system. When these systems are operated without the gas system turned on, operational procedures will be followed to insure that the FTPC is properly secured.

There will be cosmic ray and laser mode of operation in the assembly hall and the WAH. These modes will require separate connection methods for water, gas and power.

2.6.4 Assembly and Maintenance

Assembly involves transfer of the FTPC from the transportation frame to the crane fixture for installation. For inserting the FTPC into the magnet, a common rail system (for SVT, SSD and FTPC) will be used.

Maintenance work, like changes of electronic boards or readout chambers, requires the use of scaffolds and for magnet poletips to be in the retracted position. Electronic rack filters will be changed on a scheduled basis. Interlocks and sensors on the gas system will be checked according to a prescribed procedure and schedule. Sectors will be replaced with spares and repaired as needed.

2.6.5 Emergency Procedures

Emergency response procedures will be drawn up for dealing with fire, and gas and water leaks. In case of fire, power to the experimental area will be turned off. The room lights should be left on so that corrective action is easier to carry out. In the case of water leaks in the cooling system, which is unlikely due to the underpressure in the system, high and low voltages will be turned off, the circulation pump will be shut off and efforts will be made to prevent water from contaminating the FTPC electronics on the chamber and on other detectors.

2.6.6 Training and Qualification

A primary gas system operator who is responsible will always be present whenever the gas sytem is in normal operation. When the gas system is in normal operation mode there will always be a primary gas system operator who is responsible. Gas system operators who have passed training will be identified in the gas system log book, as well as future gas training data bases that are instituted for operations of this nature. Only trained operators will be allowed to start and operate the gas system. Operators and other people changing gas bottles on the gas system will be required to take the BNL compressed gas training.

A similar scheme of local expert training will be used for operation of the field cage high voltage system and the anode wire voltage supplies. Operation of these two systems, however, is much simpler but training is still required to avoid potential equipment damage.

BNL laser training will be required for anyone operating the laser sytem with the beam covers removed. These covers will only be removed for coarse alignment of the laser beam. Fine tuning can be accomplished with the beams completely contained and can be done by people who have not had BNL laser training. In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.7 Ring Imaging Cherenkov Hodoscope (RICH)

2.7.1 Overview

The RICH detector module is a rectangular structure which has a physical size of $146 \times 99 \times 24$ cm^3 ($58 \times 39 \times 9.5$ in^3) (l x w x h) and a mass of 200 kg (414 lbs). It will be contained in an aluminum box with dimensions $206 \times 127 \times 26$~cm^3 ($81 \times 50 \times 10.5$ in^3) (l × w × h). The frame of the box is constructed out of C-channel aluminum strut with a thickness of 0.5 cm. Access panels are provided to access the detector. The thickness of the skin is at minimum, 0.5 mm. The detector will be installed at mid-rapidity in the annular space between the magnet coils and the CTB modules which is 44.7 cm deep.

The RICH detector is an existing proto-type built at CERN in the context of the RD-26 project and is being made available to STAR for the initial three years of operation. The RICH detector is of modular construction of aluminum frames bolted together and sealed with Viton O-rings. A vessel containing a liquid radiator is located within these frames. It is constructed of 5 mm thick quartz which contains the chemically inert perfluorohexane (C_6F_{14}) at room temperature and pressure. A CsI coated photo-cathode with an array of Au-Ni coated Cu pads is located 2 mm above an array of proportional wires which provide amplification of ionization.

2.7.2 Safety Analysis

The RICH detector does not introduce any new types of hazards into STAR that have not been encountered in any other detector sub-system in terms of electrical, fire, toxicity hazards, etc. The RICH detector will not require any modifications to the existing safety envelope.

The RICH detector will be enclosed in an aluminum rigid gas tight box which will isolate it from the STAR detector and provide a mechanism to allow for early leak detection of gas from the MWPC. A chilled water coil will be present on the back-plane of the safety box in order to remove the heat generated by the electronics. A detailed description of the RICH detector exists in the RICH proposal, and the technical detail and development history is supplemented by the ALICE Technical Design report. The following possible hazards of the detector, present during operation and/or maintenance, can be grouped into five main categories:

- Explosion or fire due to the use of methane.
- Electrocution due to the high voltage on the wire chamber and the proximity of the liquid radiator and water cooling.
- Suffocation due to the lack of air in the volume between the Central Trigger Barrel (CTB) and the magnet coil.
- Crushing hazard due to the mounting of the RICH in a confined space and its maintenance.
- Presence of toxic/hazardous materials.

Fire and Explosion Hazards

The RICH contains 100 liters (3 oz or 80 g) of methane (CH_4) within the MWPC and is circulated through the detector at a flow rate of <25 liter hr^{-1}. RHIC OPM 5.4.11.0 provides guidelines for design criteria of experimental gas systems. The flow rate of the gas system is below the OPM requirement that the system requires personnel to be present 24 hr day^{-1} and is not considered to be a hazard by BNL.

The gas system that is utilized by the RICH detector is based very closely on that of the TPC, however it does not include the complex mixing and metering devices since a pure gas is utilized instead of a mixture. The RICH gas system shares many parts with the TPC system and was designed in close conjunction with the TPC system designers in order to capitalize on previous experience. No pumps are used in the system and all pipes used are stainless steel (304SS). A supply and exhaust line to the RICH detector is required, for both argon and methane, to two locations:

1. The beam-line position in the wide-angle hall (WAH).
2. The parking/maintenance position in the assembly hall (AH).

Since the routing and piping requirements of the TPC have already been designed and certified, additional gas lines that follow the same route are utilized.

The RICH detector is under a flow of clean, anhydrous, oxygen-free gas at all times. This gas is argon in case of storage or periods of in-operation in order to protect the CsI photo-cathode. Prolonged exposure to oxygen (or water) above the level of 20 ppm causes a deterioration of the quantum efficiency (QE) of the photo-cathodes. Since there is never any oxygen present in the detector, proceeding from storage/maintenance mode to operational mode does not require an intermediate gas purge of the detector volume with an inert gas (as does the TPC) to remove the possibility of the situation of CH_4 coming in contact with air. An oxygen monitor in the gas system will be incorporated into the RICH PLC based gas-interlock system which, upon detecting the presence of oxygen, will issue an alarm and switch the methane gas flow to the detector to argon. At any time prior to the gas flow switching to Ar, or when Ar is contained within the confines of the MWPC, no high-voltage will be present. This will also be controlled by the interlock system. This action mitigates the risk of having an ignition source present when oxygen is detected internal to the RICH module.

The RICH module is a gas tight vessel which has been helium leak tested. The RICH detector will also be encased in an additional rigid gas tight box constructed from aluminum. The benefits of an additional box are several-fold:

1. It will be flushed with nitrogen which will dilute any escaping methane gas and allow flammable gas detection in a fluid stream.
2. It will also aid in dissipating the 190~W of power generated by the front-end electronics.

3. It isolates the RICH detector from contact with air such that no oxygen should ever be in close proximity to a structure containing methane.
4. It defines a rigid envelope for the detector which provides a container on which to fix the cable, gas, and liquid feed-throughs.
5. It will contain a hard piped water cooling circuit which will facilitate the dissipation of the heat generated in the front end electronics.

With the presence of nitrogen, the leak detection requirements and procedures will be very similar to that of the TPC for P10. The flammable gas interlock will be connected to a distributed network of sensors which will monitor the RICH detector, and the gas safety box will be purged with nitrogen at all times.

The actions after detection of methane:

1. A visual alarm will indicate a potentially dangerous situation developing in the counting house if the concentration of methane reaches the point of 5% of the Lower Explosive Limit (LEL) and an audible alarm will sound if the concentration of methane reaches the point of 10%.
2. The high-voltage and low-voltage systems will be turned off immediately if the concentrations of methane in the safety box reach a level which exceed 10% of the LEL of methane.
3. The methane flow will be stopped immediately and inert gas flow will commence. The appropriate actions to take at specific concentrations will be subject to approval by the RHIC safety committee.

No further addition of forced air blowers nor the use of an active fire suppression system is necessary, because of the relatively small quantity of flammable gas in this detector.

The supply of methane will reside outside of the Wide-Angle Hall (WAH) near by the TPC supply. A flow monitor and flow restrictor will be present on the supply bottles (outside the hall) which will not allow the methane flow rate to exceed the maximum allowable detector supply of 25 liter hr^{-1}. The flow restrictor will be followed by a solenoid operating in normally closed mode.

The argon supply will operate with a similar mechanism however the valve will be in normally open mode. In the event of a power failure, the gas will automatically switch to argon flow.

Electrocution Hazard

As per STAR standards all high voltage supply lines will be coaxial with a grounded exterior conductor. RHIC OPM 5.1.5.0.1 (also specified in STAR Note 378.) specifies the use of red-jacketed RG59/U HV cables which are rated at 5 kV. The MWPC power supply cables will be contained in a metal cable tray routed from the power supply, which will be located on the first floor of the south platform. The cables from the magnet to the RICH detector will reside in a cable tray and will remain physically separated by a barrier from the liquid and gas lines.

The current rating on the HV power-supply will not exceed 2 mA which is well below the 10 mA necessary to cause serious shock and/or trauma to humans. The over-current settings will be set at the 0.1 mA level which is common to the operation of wire chambers.

The high-voltage region of the MWPC are within the volume of the detector which are not accessible during RICH operations or storage. The power supplies are LeCroy 3.5 kV supplies which are used for the TPC. All HV connectors for the feed-throughs will be of SHV type, as specified by the OPM 5.1.5.0.1, which have a rating of 6 kV.

The low-voltage power supplies provide a total of 40 A at 3.5 V. In compliance with STAR guidelines, the power will be distributed via multiple cables to ensure less than 7 A is carried in a single cable. Connections are fused at the detector on power distribution boards which are fabricated with FR4. Lemo/BNC connectors as specified by STAR/RHIC standards are used throughout.

Suffocation Hazard

During periods of storage or in-operation the MWPC will contain an argon flow as explained previously. The region between the CTB and magnet coil where the RICH will be installed is not accessible either in maintenance mode or operational mode of the STAR detector. As such any maintenance work on the detector will require the removal of the RICH (much as the SVT requirements). This implies that the RICH detector will not be accessed unless it is pulled out of the magnet enclosure. This means the detector will only be accessed in the Assembly Hall or the Wide-Angle-Hall which are both well ventilated areas so no significant risk is foreseen.

Crushing Hazard

The rail support system that the RICH utilizes has been designed for the electro-magnetic calorimeter (EMC) system which imposes much more demanding requirements than those needed for the support of the RICH module. The STAR Mechanical Design Standards and Guidelines provide for a minimum safety factor of 3 for yield stress for all structures and a safety factor of 5 if human injury would result in a failure. The RICH will not exceed 200 kg (400 lbs). It will be supported by three legs fastened to two EMC support rails. In contrast a single calorimeter module has a mass of 916 kg (2100 lbs) and will be supported by a single rail. The modelling of the deformations of the rails with a calorimeter module are thus much more severe than those expected with the RICH. As such this is not considered to be a significant hazard.

In order to install and extract the RICH detector from the STAR magnet, an installation tool is provided that is mounted to the magnet body and rail support system within the magnet. This tool will not only allow insertion and extraction from the magnet, but will also provide a mount where the detector can be accessed for maintenance. It will be inspected and tested at BNL before usage. The overhead cranes will also be required for manipulation of the detector in the installation procedures. Compliance with BNL rigging and maintenance procedures will be followed to minimize any risk.

Toxic and Hazardous Material

The RICH is an existing and operational detector. The construction of the RICH module has been according to CERN standards which does not allow for the use of any toxic or hazardous materials. The detector does not introduce any material components in its construction which are new to the STAR/BNL environment with the exception of the radiator liquid perfluorohexane (C_6F_{14} trade-name: FluoroInert FC-72). Perfluorohexane is a chemically inert, non-aromatic (not derived from benzene) saturated fluorocarbon that is chlorine free. It is colorless, odorless liquid at room temperature and has a boiling point of 51^{o}C (122^{o}F). It is non-flammable and not toxic and no special equipment beyond normal industrial hygiene is recommended for its usage and handling. No special precautions for first aid beyond common laboratory practices for removal of foreign materials from skin and eyes are recommended. No government regulations exist for its transportation on public roadways, railways, or airways.

Perfluorohexane is used in the electronics industry as a cleaning solvent which is sold commercially as a non-ozone depleting alternative to chloro-fluoro-carbons. This is reflected in the guidelines for its disposal where small quantities are recommended to be evaporated in a fume hood or sent to a land-fill.

The presence of a perfluorohexane leak from the quartz cavities will be detected by two independent methods. First a small proportional chamber will monitor the amplitude of a signal on the output gas line of the MWPC. Perfluorohexane is an electro-negative gas and the signal amplitude is expected to decrease with concentrations even on the order of several 10s of ppm. This method will be sensitive to both large and small leaks. In the case of a catastrophic failure of the quartz liquid containment vessels, the flow rate of the fluid will immediately drop to zero. This will be detectable from the flow monitors which are contained on the liquid recirculation system. When located inside the STAR detector, the radiators will normally contain fluid.

2.7.3 Modes of Operation

Under normal operating conditions, all four sub-systems will be operating simultaneously:

- Low voltage electronics power.
- High voltage MWPC power.
- MWPC gas system.
- Liquid radiator recirculation system.

It is not foreseen to operate the detector for any extended time when the TPC is also not in operation. Other modes of operation will include only diagnostic and maintenance jobs where operating each subsystem independently may be required for testing and diagnostics. At all times there must by clean anhydrous gas flow across the CsI photo-cathode. When the detector is not operating, the flow will be argon.

2.7.4 Assembly and Maintenance

The RICH is installed within the 44.7 cm deep annular region between the central trigger barrel and the magnet iron at the 5 o'clock position. As such it is treated as completely inaccessible unless it is removed from the STAR detector. The installation fixture used to install and remove the

RICH detector from STAR will allow access to the front and back of the RICH detector when removed from STAR.

2.7.5 Emergency Procedures

Emergency procedures are currently under consideration for dealing with fluid (C_6F_{14}) and gas leaks, along with fire. In any instance of system or subsystem failure or warning, such as the detection of any flammable gas outside the RICH safety box, an elevated temperature reading, the power to the detector will immediately be cut and the gas flow changed from methane to argon. This will be considered the automatic purge mode.

<u>Fire</u>

The detection of fire and/or dangerous conditions associated with fire is implemented with temperature, heat, and combustible materials/products detectors. The precursor to combustion would be most likely to occur in the electronics of the detector. The first line of defense is temperature monitoring in conjunction with electrical fuses. The electronics will be protected with a fuse rated at 1 A and 3 V. Furthermore multiple temperature measurements will be made within the gas containment safety box at various locations. This will be supplemented with current measurements that monitor the operating conditions of the electronics. In the case of an extreme current or temperature reading, the low voltage power, as well as the high voltage power, where warranted will be turned off. This removes the heat generation sources as well as the only ignition source within the detector. The High-Sensitivity-Smoke detectors system (HSS) will be incorporated into the STAR-RICH control systems via interlocks. If any situation within the STAR detector produces an alarm condition, both the low-voltage and high-voltage power may be cut. It is also necessary that upon reception of an alarm condition, the detector be immediately switched to an inert gas supply (Ar) to minimize the amount of combustible material within the RICH envelope.

<u>Radiator Fluid Leak</u>

In the case of a perfluorohexane fluid leak, the response will be different according the the size of the breach. In the case of a small leak, the recirculation pump will be turned off. If fluid is being discharged external to the gas safety box, the radiators and liquid supply lines may be drained. In the case of a large breach, the pump is immediately turned off and the fluid still remaining in the radiator vessels will be drained into the main reservoir tank so that corrective action can be carried out.

Water Leak

In order to increase the efficiency of the cooling and to protect against a temperature gradient in the detector, the back panel of the gas safety box will contain a cooling coil through which chilled water, supplied from the TPC cooling system will be present. The system will be constructed from hard tubing instead of flexible hose which makes it resistant to punctures.

2.8 Detector Electronics

2.8.1 Front End Electronics

2.8.1.1 Overview

The Front End Electronics (FEE) for the STAR detector comprises the electronics necessary to instrument the TPC endcaps and provide digitized information to the data acquisition system. It is composed of four major subsystems: (1) the end cap electronics, (2) the low voltage power supply system, (3) signal cabling for data acquisition, clock/trigger distribution and slow controls and (4) cabling for low voltage power distribution.   The analysis of the FEE does not include electronics such as the high-voltage systems, slow controls for gas handling or monitoring or other functions needed for proper operation of the TPC. These are analyzed in section 4.5.2 which discusses the TPC.

The TPC endcap electronics are mounted on the 12 inner+outer sectors of each TPC endcap. The TPC endcap sectors are mounted on an aluminum strong back which is, in turn, mounted on the TPC wheel that provides the basic structural support. Each endcap sector is equipped with electronics designed to amplify, digitize and transmit signals from the TPC pad plane to the data acquisition system. Within each strongback, 32 channels of electronics are mounted on each “FEE card” that fits into the connectors on the strongback and couples directly to the TPC pad plane.

Up to 36 FEE cards are connected to a “Readout board” for data collection and transmission to the data acquisition system in the counting house. The readout board support frame mounts to the TPC wheel. Readout boards are actually pairs of boards, with a master board containing the communications link to DAQ, slow controls interface, clock/trigger interface, and power distribution for 20 FEE cards. A ‘slave’ board extends the capacity of each readout pair by up to 16 additional FEE cards. The slave boards either plug into the master boards directly (outer TPC sectors) or via multiconductor flat cables (inner TPC sectors). Each group of four FEE cards has it’s own +5V and -5V voltage regulators and are connected to the Readout board via two 50-conductor flat cables.

The TPC Endcap low voltage power supplies reside in a group of eight electronics racks located on the second level of the south platform. Each rack contains six power supply chassis; each chassis holds three Kepco 300 Series ferroresonant (voltage stabilized) power supplies. Each supply provides + and - 8.5VDC @ up to 15A for one readout board. Each rack also includes one chilled-water heat exchanger and blower unit. Circuit breakers are located at the top of each rack. Water-leak and smoke detection as well as fire suppression within these racks are discussed in the conventional systems section of this document.

The front end electronics (FEE) for the STAR TPC receives signals from the 136,600 pads on the TPC, amplifies them, shapes them, and digitizes them with a 512 time sample, 6/12 MHz, 10 bit waveform digitization system.

2.8.1.2 Safety Analysis

Hazards

The major hazards related to FEE are electrical shock and fire hazards. The power supply chassis use 120VAC. The on-chamber electronics are supplied from relatively high capacity power supplies making it possible to produce an ignition source near the TPC gas volume in the event of a component failure.

Safety Systems

Detection

The electrical shock hazard associated with the 120VAC power input to the rack-mounted low voltage power supplies is mitigated by providing a complete metal enclosure around each chassis. A cautionary label is located near the AC input connector of the chassis and also on the control circuit board inside the enclosure.

The fire hazard posed by the low voltage power distribution cables is mitigated by the use of TC rated cable in the cable trays (as per NEC) and the inclusion of individual fuses for every power lead (built into the power supply chassis.) All other (signal) cables in the cable trays are rated 300V CL2. All meet the relevant flammability requirements.

The danger of fire caused by an electronics component failure on the endcaps is mitigated by the inclusion of fuses on every secondary circuit (nearly 4000 in all) which will limit the total power available at any one point to of-order 15 Watts. All voltages and cable currents are monitored via slow-controls which has the ability to shutdown any power supply. To protect the valuable electronics from overheating in the event of cooling water loss, each readout board is equipped with a 60°C thermal switch which removes all power to the readout board circuitry and all associated FEE cards. Finally, all primary AC power in the racks housing the FEE power supplies will be interlocked with a high- sensitivity smoke detector in each endcap.

Mitigation

Administrative Controls

Appropriate administrative controls will be provided to insure that the FEE system is properly protected against operator error. A set of standard operating procedures will be provided, clearly defining safe and appropriate modes of operation and maintenance.

2.8.1.3 Modes of Operation

The FEE system will have a number of different modes of operation. These include normal data taking as well as a variety of calibration modes. The calibration modes use an internal calibration pulser, as well as various TPC related calibration signals, such as the ground plane pulser or laser events. From the safety standpoint, these modes of operation are equivalent; calibration modes are selected via the clock and trigger fanout, and no significant voltages or currents depend on the mode.

2.8.1.4 Assembly and Maintenance

Appropriate administrative controls will be provided to insure that the FEE system is properly protected against operator error during assembly. A set of standard operating procedures will be provided, clearly defining safe and appropriate modes of operation and maintenance. These procedures will require that power be turned off before any cables are disconnected or reconnected.

2.8.1.5 Emergency Procedures

In an emergency, procedures require power to be turned off. This will eliminate all electrical hazards, and all sources of heat.

2.8.1.6 Maintenance

The FEE system should require minimal maintenance. FEE Cards, readout boards, and power supplies will occasionally fail and need to be replaced. With the power removed, there are no special hazards during maintenance.

2.8.1.7 Training and Qualifications

A set of standard operating procedures will be provided, specifying appropriate action to be taken in the event of normal and abnormal FEE actions. All personnel working with FEE will be trained in these procedures. In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.8.2 Data Acquisition Systems

2.8.2.1 Overview

The data acquisition (DAQ) system for the TPC consists of several parts: (1) receiver boards and crates, (2) the third-level trigger, (3) the data logger, and (4) the workstation interfaces.

The receiver crates contain the receiver boards and the third-level trigger CPUs. The receiver crates will be implemented using an industry standard backplane (VME). The purpose of the receiver boards and trigger processors is to select data for analysis and logging on tape.

The tape logging device will make use of a commercially interfaced system. The human interface to the DAQ system will take place through workstations.

2.8.2.3 Safety Analysis

Many of the hazards and mitagations discussed in regard to the FEE electronics (section 4.8.1) are applicable to the DAQ system and will not be discussed in detail. Most of the DAQ system will be housed in VME crates in racks that are in a DAQ room. The high value of the DAQ system and the lengthy delays possible in the event of the loss of DAQ components argues for fire detection and suppression. The principal hazards identified for DAQ are (1) electrical and (2) fire hazards.

The use of cabling presents an obvious fire hazard. This can be mitigated by strict adherence to the requirements of NFPA-70 (NEC) and the RHIC OPM 5.1.5.0.1.

Selection of materials (i.e. wire insulation, terminal blocks, barriers, structural supports etc. will be on the basis of the materials non-flame spreading characteristics as indicated by UL # 83. Printed circuit boards fabricated by DAQ use FR4 material.

The VME crates contain power supplies with high current capabilities (200A @ 5V). This poses a potential personnel hazard in the event that a metal tool is dropped across the 5V buss, possibly resulting in eye injuries. To mitigate this problem, all of the crates delivered by the manufacturer have been modified to add a mylar shield covering all of the low-voltage delivery system.

Racks containing VME crates will be monitored by a HSSD system (see section 4.1.4) and be provided with power disconnects to interrupt power in the event of incipient fire or smoke detection. Crates containing essential electronic systems will be provided with a fire suppression system. All racks will be provided with overcurrent-overvoltage protection as per requirements of the RHIC OPM section 5.1.5.0.1.

2.8.3 Trigger

2.8.3.1 Overview

The STAR trigger consists of four detector assemblies, the Central Trigger Barrel (CTB), Zero Degree Calorimeter (ZDC), Multiwire Chamber (MWC), Vertex Position Detector (VPD), and the electronics that service these to provide trigger signals for the rest of STAR. There are no gases or liquids in the trigger.

The heart of the STAR detector system is the TPC. This detector is designed to return data on dE/dx and particle trajectories in the pseudo-rapidity region of $-2< \eta <2$, from which we hope to glean an unambiguous signal of the formation of a quark-gluon plasma (QGP). The signature of the QGP is unknown, however, making it difficult to design a trigger to select collisions in which a plasma has formed. Therefore we have designed a trigger that is flexible, that can learn the normal distributions of particles within events, and that can be programmed to select events that are outside the normal distributions.

The trigger system also consists of the electronics for data processing and triggering functions and the interfaces to the detector subsystems and DAQ.

CTB: There are 120 trays of the Central Trigger Barrel, each containing two scintillator slats with each slat viewed by a single photomultiplier. The trays are arrayed around the TPC in a barrel of radius ~2m and length ~4m. Each slat delivers light according to dE/dx in the scintillator. The overall track multiplicity in each slat is proportional to the total light generated. Consequently, an ADC on each PMT gives an indication of total charged particle multiplicity in the region from $-1< \eta <1$ in the CTB.

2.8.3.2 Safety Analysis

We describe below the possible hazards, their mitigation, and the administrative controls in place, for the STAR trigger system.

Hazards

The only known potential hazards in the Trigger subsystem are electrical in origin, relating to the local use of high voltage and the possibility of fire initiated via electrical energy.

<u>High Voltage</u>

Each CTB tray has two PMTs which operate at ~2kV. Each ZDC has two PMTs mounted in the “open air”. The types of hazards represented by this high voltage include shock hazards and spark hazards.

<u>Fire</u>

There are three places within the trigger where electrical fire may originate: in the CTB trays, in the cables, and in the rack-mounted electronics.

1. The CTB trays contain photomutiplier tube (PMT) bases that dissipate approximately 2W of energy in each tray.
2. The cables carrying electrical energy to the CTB trays and to the ZDC PMTs may overheat if subjected to larger current than their ratings.
3. The rack-mounted electronics consists of three VME crates containing specially fabricated Digitizer Boards (CDB), Data Storage and Manipulation (DSM) boards,

a Trigger Control Unit (TCU), and commercial VME processors (CPU). Each CDB, DSM, TCU, or CPU dissipates approximately 25W of energy.

Safety Systems

The following Safety systems are in place to deal with the above-identified hazards. These include detection, mitigation, and administrative controls for each identified hazard.

Detection

<u>High Voltage</u>

The PMT high voltage is generated on the platform in commercial hardware (LeCroy 1440), and delivered to the trays via RG59 cable with SHV connectors. Voltage hazards are detected via continuous monitoring of the source voltage from which the high voltage is derived and continuous monitoring of the output signal from each PMT, which is typically linearly related to the high voltage applied to the PMT.

<u>Fire</u>

The following fire detection systems are employed within the trigger.

1. The current flowing in each power cable is monitored continuously. Smoke detectors are placed at strategic locations throughout the system.
2. Local temperature in each trigger rack is continuously monitored. Smoke detectors are placed above each trigger rack.

Mitigation

<u>High Voltage</u>

The high voltage source is completely contained within non-conducting housings. In addition, the CTB PMT bases containing the high voltage distribution circuits are completely enclosed within the aluminum housing trays.

<u>Fire</u>

The following precautions have been taken to mitigate the effects of fire in the trigger system.

1. Each CTB tray is nearly completely sealed to prevent buildup of any gases (source unknown) that could cause a fire. While the plastic scintillator in the trays is potentially flammable, the trays themselves are aluminum to both dissipate heat from

the inside as well as prevent flame from reaching the material inside. The tray electronics are placed to have an unobstructed convective and radiative heat couple to the aluminum tray housing to facilitate heat dissipation.

2. The power cables are separated from all other cables, thereby isolating the potential heat sources that could cause a fire. Each source and each sink is fused to prevent current overload in the system.

3. The Trigger racks are located in a fire-protected area within the STAR platform or electronics house.

<u>Administrative Controls</u>

Temperature and current monitors are recorded periodically into the data stream with watchdog alarms for out-of-range measurements.

2.8.3.3 Modes of Operation

The trigger has three modes of operation: stand alone, independent streams, and fully coupled streams.

2.8.3.4 Assembly and Maintenance

The Trigger assembly is documented in a separate appendix.

2.8.3.5 Emergency Procedures

In the event of overcurrent within any portion of the trigger, the system is automatically shut down if the condition is outside an alarm interval. The operator is informed of approaching problems as the temperature or current indicators go out of bounds through the STAR standard alarm procedure.

2.8.3.6 Maintenance

There are no consumables in the Trigger system, so that there are no automatic maintenance issues. Repairs will be accomplished by trained technicians at BNL, or, in the event of a more complex problem, the units will be returned to Rice (CTB mechanical) or LBNL (all electronics) for expert repair.

2.8.3.7 Training and Qualifications

The trigger will have a web-based tutorial for general training. All operators will be required to take a short Trigger operations course, signing appropriate documents on completion, as in the STAR standard fashion. In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.8.4 Slow Controls

2.8.4.1 Overview

Slow controls will be carried out using EPICS (Experimental Physics and Industrial Control System). The selection of the EPICS environment predefines the hardware configuration of the Controls System. The system hardware consists of 68040 Motorola processors in VME crates and, wherever possible, commercially available industrial interfaces and programmable controllers. The monitoring tasks and system control are distributed on SUN workstations. The workstations and VME crates are networked with Ethernet. The Slow Controls group provides a workstation for central controls and monitoring. It is the function of each of the subsystems to provide any interfaces, supported sub-buses, cables and converters and a workstation that provides the auxiliary, subsystem operator interface if required. Subsystems have been designed, where possible, to use hardware which is currently supported by EPICS. Interfaces to non-EPICS subsystems (Magnet, TPC gas system, RHIC controls) should be carried out using a standard interface (CDEV).

The Controls System is not intended to provide personnel safety for the experiment. But since it handles information from all the subsystems and is sensitive to subsystem parameter changes, it can provide an early warning of problems and enhance system safety significantly.

2.8.4.2 Safety Analysis

All changes in the system parameters that lead to situations that jeopardize safety of the facility should generate alarms.

Controls System must monitor status of all the interlocks in the detector system on a second by second basis.

All alarms related to safety should be of the highest level ("major" alarms).

Hazards

The following electrical and fire hazards and steps to reduce these hazards have been identified for the Slow Controls. The VME crate power supplies can provide large currents to objects creating a short. Over-voltage and current conditions will be detected locally by internal Slow Controls monitoring. Locally, over-voltage and over-current conditions will trigger an automatic shutdown of the power supply requiring the source power to be turned off and back on at the rack, or remotely by Slow Controls via a reset. Fan operation will be monitored locally and the unit will be shut down automatically if the fan becomes inoperative. The temperature of the racks will be monitored by Slow Controls which provides an alarm with the option of shutdown if the temperature exceeds pre-determined limits. VME busses will be not be exposed (screen on the back side of the crate, panels on the front). Operators will be informed of abnormal conditions and may perform manual adjustment or automatic shutdown of affected components. An alarm hierarchy and a system wide display will be used to distinguish between small problems and serious conditions. The racks housing the slow controls crates will be enclosed for the purpose of controlling room heat loads; this also provides an additional benefit for fire protection because the control of air flow in the cabinets limits the introduction of outside air into the cabinets to support combustion and limits flame spread. Automatic shutdown of power to a whole rack will occur on smoke detection or excessive temperature in a whole rack.

The use of cabling presents an obvious fire hazard. Internal cabling (ethernet and serial connections) will use general purpose communication cables which are permitted per RHIC OPM 5.1.5.0.1. The possibility exists that these copper cables can be replaced with fiber optic cables. The cables to the front end modules in slow controls are the responsibility of the individual detector subsystems.

2.9 Computing

2.9.1 Overview

The computing system at the STAR experiment encompasses the computing systems and activity directed at controlling and monitoring the acquisition of STAR data. Safety concerns are limited to those of handling conventional workstation-scale commercial computing equipment:

electrical and fire hazards. The computing system relies on the fire detection and mitigation facilities of the building infrastructure.

The STAR Computing System encompasses on-line and off-line computing and software. Off-line computing is a distributed endeavor taking place at collaboration institutes and in individuals' offices, and is not a concern for this document. On-line computing takes place at the experiment, with facilities installed in the experiment control room and the trailer. Activity is all computer-based, and encompasses run control, on-line monitoring, subsystem run control, on-line logging and calibration database, configuration management, and data flow to on-line systems (monitoring, calibration). Work takes place at computer workstations installed in the control room.

2.9.2 Safety Analysis

2.9.2.1 Hazards

Computing system activity involves work at computer workstations and installation and maintenance of the infrastructure that supports them: networking cables, networking hardware, printers, etc. All equipment is conventional commercially procured equipment and is appropriately fused. Computing equipment is small scale (workstations and small servers) with power supplies in the several hundred watt range. Occasional opening of electrical cabinets or appliances is required.

2.9.2.2 Safety Systems

No dedicated safety systems are employed in the computing system. The computing system relies on the fire hazard detection and mitigation facilities of the building infrastructure.

2.9.3 Modes of Operation

The computing system operates in the stable steady state of a conventional computing installation.

2.9.4 Assembly and Maintenance

As mentioned, assembly and maintenance can involve the hazard of opened electrical appliances. Standard precautions of limiting such activity to qualified personnel and disconnecting equipment from power sources are taken.

2.9.5 Emergency Procedures

An emergency power cutoff will be provided in the control room.

2.9.6 Maintenance

Computing has no dedicated safety systems to maintain.

2.9.7 Training and Qualifications

All on-line shift takers and on-line computing system users will take a short training course augmented by web-based tutorials. Shift takers will participate in on-site mentored training before being qualified for shift duty. In addition to the training requirements specified in section 1.9, staff members will receive formal BNL training, as appropriate, for their work assignment.

2.10 Radiation Hazards

2.10.1 Safety Analysis

2.10.1.1 Hazards

The expected radiation flux at the STAR interaction region, and the radiation flux expected in the DBA fault study have been documented through a series of technical notes and memoranda. Rather than reproducing here the information contained in these documents, they will be referenced as appropriate. The local shielding requirements for the STAR detector were first determined in a study that is contained in RHIC Detector Note 5 (Appendix 37). The radiation load was simulated for the "worst case" fault, for the beam-beam interactions in the STAR hall, and for beam–gas interactions in the STAR beam pipe. The worst case fault consisted of the loss of the entire beam stored in one of the collider rings on a single "DX" magnet. The DX magnet is the one closest to the STAR interaction hall. It was determined that the radiation load from the worst case fault was much larger than the steady state radiation from the beam-beam and beam-gas interactions. Therefore we will deal here with mitigating the radiation hazard from this worst case fault.

There will be a number of radioactive sources used for detector testing and calibration. These sources will be primarily (if not exclusively) sealed radioactive sources. Safety measures to mitigate the safety hazards associated with these sources will also be described.

2.10.1.2 Mitigation

The radiation dose from collider operations was parameterized as a function of the distance of the shielding wall from the beam line, the thickness of the shield wall, and the attenuation lengths of the shield wall material. For the particular case of the STAR detector and the Wide Angle Hall, the radiation dose behind a shield wall which separates the WAH and the Assembly Building is given by:

Dose (rem) $=(410/R^2) * \exp(-thk/\lambda)$

where thk is the thickness of the wall in meters (m), λ is the attenuation length of the shielding material (m), and R is the distance from the center of the beam line to the back (farthest from beam line) surface of the shielding wall.

The shield wall for STAR is designed to mitigate the prompt radiation potential at four times the design intensity. The worst case fault radiation hazard scales with the intensity.

For the shield wall configuration which has been designed for use at the STAR site to separate the WAH from the Assembly Building, using the equation above, a DBA Fault dose of approximately 0.08 rem is calculated. This is well below the fault design criteria for radiation workers in a high occupancy region (0.5 rem/yr). The input values for the calculation are:

thk = 1.68 m

λ = 0.502 m (light/normal concrete)

R = 13.7 m

For future upgrades, with four times original the machine intensity, one merely multiplies the result above by four to get 0.32 rem.

There are personnel access labyrinths on both the east and west sides of the opening between the WAH and the Assembly Building. The design of these labyrinths was reviewed by the Radiation Safety Committee and approved for final design and construction (Appendices 38, 44 amd 45). Both of these labyrinths will have gates, which prevent access to the WAH while there is beam circulating in the Collider. The west labyrinth door will be configured to permit routine access from the Assembly Building to the WAH. The other labyrinth on the east side will be locked from the Assembly Building side, but passable from the WAH side as a second route only for emergency egress from the WAH to the Assembly Building.

In addition to the radiation shielding described above, there will be a number of beam crash off buttons located around the walls of the WAH as well as on the STAR electronics platforms.

A number of radioactive sources, primarily sealed sources, which will be used in detector testing and calibration. There is a well-defined set of procedures, complying with the BNL RadCon Manual, for dealing with these types of radioactive sources which will be followed. Some of the key aspects of these procedures are:

- the identification of a source custodian, with ultimate responsibility for the inventory, control and use of the sources
- requirements for secure locations where the sources are to be stored when not in use
- sign out requirements for personnel using the sources
- regular inventory and checking of the sources

Examples of the type of sources that will be used at the STAR site are Sr-90 with an activity level of 4.2×10^{-5} Ci and Fe-55 with an activity level of 3.45×10^{-5} Ci.

2.10.1.3 Assembly/Maintenance

The approved design of the STAR shield wall calls for a single layer, stacked block wall. As part of the analysis and approval of the shield wall design a study was performed (Appendix 39) on the effect of the cracks between the blocks which make up the wall. While the results of the study showed the radiation flux through these cracks to be quite low it was determined that efforts must be made to maintain the maximum crack width in the stacked wall at 3/8 of an inch or less. To achieve this tolerance an optimization process will be undertaken on the combination and placement of the blocks making up the wall. Once a particular block placement plan is determined a labeling scheme will be developed and put in place so that the wall is constructed with the same block placements on every assembly of the wall. Pictures will be taken of the wall after each assembly to document that this block placement plan was correctly followed.

2.11 Detector Installation and Maintenance

2.11.1 Overview

The scope of this subsystem includes labor required for installing and testing the baseline detector components of STAR in the WAH, Assembly Building, and associated facility buildings at RHIC. The subsystem is subdivided into four elements: Installation, Test, General Purpose Installation and Test Equipment, and Subsystem Management. This subsystem provides both the technical and trade resources and general equipment for installation and test of each subsystem. Memoranda of Understanding have been generated defining the interfaces between this subsystem and all other subsystems within STAR in detail. Additionally, STAR/RHIC Project has entered into a Memorandum of Understanding with the AGS Dept./EP&S Div. to provide the necessary trained resources, skilled technical and assigned trade support, for assembly and installation of the STAR magnet, individual detector subsystems, conventional systems, and other detector related items at the STAR facilities.

2.11.2 Safety Analysis

<u>Hazards and Mitigation</u>

Many of the hazards that will be encountered by those technical and trade resources provided for by this subsystem and working at the STAR Detector/Facilities are typical of those dealt with routinely at other BNL accellerator experimental areas. It is the responsibility of each individual subsystem to plan their project tasks and define the associated hazards and safety systems, while it is the responsibility of this subsystem to provide and coordinate the required resources within the scope of the project plan. Provided below is a general overview of the safety hazards and systems that will be encountered, while specific safety hazard issues are left to each individual subsystem.

Mechanical hazards, in general, are those encountered when rigging and positioning large heavy components for assembly to heights of forty feet off the floor. This work requires the use of the overhead bridge crane, forklift, and man-lifts and the potential exists for component damage, crushing of personnel, dropping of hand tools, or accidental fall. To mitigate these mechanical hazards each subsystem must provide installation procedures and rigging procedures for all hoisting and/or rigging of this experimental equipment for installation and assembly at STAR facilities. Rigging procedures are reviewed by the Experiment Safety Committee. Only trained and qualified personnel will operate cranes, forklifts, or man-lifts, and all are required to wear hard-hats and harnesses as per appropriate standards. This subsystem in conjunction with the cognizant activity managers will coordinate and prioritize all work to minimize the interaction of personnel working above others.

Electrical hazards exist during the installation, maintenance, repair, and testing of electrically powered experimental equipment; i.e. magnet power supplies, TPC high voltage, electronics racks.

These associated hazards and safety systems shall be defined by each individual subsystem along with the necessary procedures and checklists. Only those qualified personnel that have received the proper training; i.e., lockout tagout, working hot, shall be allowed to perform such tasks.

2.11.3 Detector Installation and Test Plan

The STAR detector was built in the newly constructed 6 o'clock Assembly Building and moves on rails into the WAH for operation. Each detector subsystem was delivered, assembled, installed, cabled, and tested in the Assembly Building. The detector with its electronics platforms is then rolled into place into the complete interaction region, the vacuum pipe connected, and a radiation shield wall erected on the north opening of the WAH. At this point, the detector is ready for testing and operation.

The initial assembly of the STAR detector in the Assembly Building is the solenoid magnet along with power supply testing and magnetic field mapping as described in the STAR Magnet section of the document. In conjunction with the magnet assembly, detector conventional systems; i.e., modified chilled water, clean/conventional electric power, electronic racks and platforms, will be installed at the facilities. After the field mapping is complete, the poletips will be removed on their support carriages, and a TPC installation fixture will be installed through the magnet. This allows the TPC, without Central Trigger Barrel (CTB) modules, to be rolled along the fixture into place inside the magnet, where it is then mounted to the magnet end rings. The fixture will then be withdrawn from the magnet.

After the TPC is installed and aligned, the CTB and SVT support cone will be installed. The SVT, TPC, and CTB cables and utilities are then routed from the platforms through the cableways and terminated in the detector. After cabling to the electronics platforms is completed, pole tips will be replaced and the detector will then be ready for testing.

After testing, the detector, together with its electronics platforms, will be rolled into the WAH. This will be accomplished with a hydraulic jacking system capable of driving horizontally for movement from building to building; and vertically to raise the detector to the IR and electrically isolate it from building ground. This method of positioning the detector is similar to that used to move other large detectors such as SLD, and D0.

When the detector is aligned and secured with seismic restraints at the IR, all utility connections such as magnet power and water, clean/conventional power, and beam vacuum will be made. The shield wall will be erected and all detector subsystem will then be powered and tested prior to experimental operations approval.

2.11.4 Detector Maintenance Procedures

There are two service scenarios which may occur. The first scenario requires the removal of the detector from the WAH. This would be required in the case where a sub-system needs major service, such as a coil failure, or a time-consuming upgrade. The beampipe is disconnected, the shield wall disassembled, and the detector rolled into the Assembly Building As soon as the detector is in the Assembly Building, the replacement beampipe is installed and the shielding erected. It is estimated that the RHIC accelerator would be operational in about 2-3 weeks.

The second type of service scenario is where quick access is needed to service SVT, TPC, and CTB electronics, or for replacement of a TPC sector and/or CTB module(s). In this second scenario, the poletip(s) are retracted while the beampipe is left undisturbed. The service is completed and the pole tips replaced with the detector ready for operation. This short term access is dependent on the type of service required but would be considered for a two day to two week shutdown period

P. PHENIX DETECTOR

1.0 Introduction

This section details the safety hazards identified during this assessment of the PHENIX experiment. Some of the hazards associated with the PHENIX experiment are conventional ones normally associated with scientific or industrial facilities. These are routinely encountered and accepted by the scientific community and are usually are dealt with by strict adherence to national codes and standards. These include electrical hazards, conventional hazards, natural phenomena hazards and hazardous or toxic materials. The unusual hazards posed by PHENIX are flammable gas, radiation (including materials activation), magnetic field, and laser hazards. Table 4-P-1 summarizes the hazards associated with the PHENIX detector.

TABLE 4-P-1

Overview of Hazards Associated with the PHENIX Detector System

Subsystem (Reference)	Hazard Type	Detection/Mitigation
Magnets (2.1.3)	Magnetic Fields	Administrative Controls Barriers Signage LOTO
	Fire Issues	HSSD
	Loss of Cooling	Flow Sensor Temp Sensors Buss Resistance Interlocks
	Water Leakage	Water Mats
	Electric (LV) High Current	Interlocks Fusing LOTO Barriers Procedures
MVD (2.2.2.1)	Magnetic Fields	Administrative Controls, LOTO
	Fire Issues	HSSD
	Working at Heights	Approved Lift Platform Training PPE
	Electric (HV)	A
	Electric (LV)	B
BBC (2.2.2.2)	Magnetic Fields	Administrative Controls LOTO
	Fire Issues	HSSD Temp. Sensors
	Laser	Interlocks Procedures Training PPE
	Electric (HV)	A

Subsystem (Reference)	Hazard Type	Detection/Mitigation
	Electric (LV)	B
Tracking System PC, DC, TEC (2.2.3.4)	Fire Issues	HSSD
	Electric (HV)	A
	Electric (LV)	B
	Flammable Gas	C
RICH (2.2.4)	Fire Issues	HSSD
	Electric (HV)	A
	Electric (LV)	B
	Flammable Gas	C Oxygen Detection 2 Levels of Over Pressure Protection Kapton/Vinyl Window Protection Nitrogen Inertion Emergency CO_2 Purge Buffer Volume
TOF (2.2.5.2)	Fire Issues	HSSD Fire Suppression
	Laser	Interlocks Procedures Training PPE
	Electric (HV)	A
	Electric (LV)	B (Exception) Non CL2 Signal Cables approved with fire suppression

Subsystem (Reference)	Hazard Type	Detection/Mitigation
EM CAL PbGl, PbSc (2.2.6.2)	Fire Issues	Lead Heat Absorption Encased in Stainless Steel Boxes Fire Suppression (PbGl)
	Laser	Interlocks Procedures Training PPE
	Electric (HV)	A
	Electric (LV)	B (Exception) Non CL2 Signal Cables approved with fire suppression
Muon Arms MuID, MuTr (2.2.7.3)	Fire Issues	HSSD Isolated Location
	ODH	Procedures LOTO Training
	Electric (HV)	A
	Electric (LV)	B
	Flammable Gas	C
Electronics Racks (2.3.1.5)	Fire Issues	Temperature Sensors Smoke Detectors Positive Pressure
	Electric (HV or LV)	Voltage Monitoring, fully grounded, interlocked with flammable gas monitoring system Automatic and manual trip for rack AC power Local and remote trip for AC power

TABLE 4-P-1 (cont'd)

Common System Information

Hazard	Detection / Mitigation
A Electric (HV)	Rated Cables Rated Connectors Circuit Protection Current Limit Protection interlocks with flammable gas monitoring system LOTO Procedures
B Electric (LV)	Rated Cables Rated Connectors Fused Current Limiting Interlocks Thermal Protected Monitoring
C Flammable Gas	Detection Monitors Interlock with Electronics Flow Restrictors Over-Pressure / Under-Pressure Protection Supply / Return Flow Rate Comparison Blow Down Ports Check Valves Flash Arrester Gas Compatibility LOTO Ventilation

Few of the hazards pose an on-site impact which is sufficiently damaging to the facility that it cannot be returned to an operational state. The exception is an accident at the level of the DBA discussed below, which could involve a significant portion of the flammable gas inventory at PHENIX. Safety systems and procedures are designed to control and mitigate the hazards outlined in this document.

1.1 Flammable Gas Hazards

There are flammable gas hazards inherent in the utilization of ethane, methane or isobutane in the tracking chambers, muon tracking and RICH sub-systems. Combustion of the large inventory ($100m^3$) of flammable gas comprises the Design Basis Accident for PHENIX and is discussed in detail therein. General flammable gas hazards are discussed in Section 2.3.2.2.

1.2 Electrical Safety

Potential electrical hazards (and some of the fire hazards (sparking, shorts etc.)) are associated with: (1) high current DC power supplies and distribution system used to power the magnets, (2) low voltage DC systems used to power electronics for signal collection, monitoring and data processing, (3) high voltage power supplies and distribution networks providing operating voltages to detector systems, and (4) 480/208/120V 60 Hz power distribution system.

The hazards associated with the utility electrical systems are typical electrical hazards like electric shock and fire hazards. Other electrical hazards are stored energy and ground faults. Hazards associated with HVAC systems and cooling water distribution and supply systems are those associated with loss-of-coolant incidents and include potentials for damage to detector systems, materials and electronics. Loss of magnet and equipment cooling water also pose secondary fire or electrical shock hazards due to damage to electrical systems. In addition, loss of integrity of the cooling water distribution systems (leakage) can produce flooding or water spillage that has the potential for costly detector damage, loss of scientific data and creation of fire or electrical shock hazards.

1.3 Fire Prevention/Detection/Suppression

Fire hazards associated with PHENIX are discussed in detail in section U, along with provisions designed to ensure compliance with Life Safety and other DOE requirements.

1.4 High Pressure, Oxygen Deficiency Hazards (ODH) and Confined Spaces

PHENIX uses significant amounts of gases in detectors and compressed gas or cryogenic liquids will be stored at the facility to meet the needs of the experiment. Oxygen deficiency hazards (ODH) are possible because of large volumes of N2 or CO2 used to purge/inert detectors. The Muon Magnets are identified as confined spaces and may not be entered after detectors are installed unless the magnet is opened by removal of the enclosing “lampshade” panels. General oxygen deficiency hazards are discussed in Section 2.3.2.3. General compressed gas hazards are discussed in Section 2.3.2.4.

1.5 Conventional Hazards

Conventional safety hazards associated with PHENIX do not differ in magnitude or kind from the conventional safety hazards encountered and accepted in other high energy physics experimental areas at Brookhaven or in industrial or commercial business settings nationwide.

1.6 Hazardous and Toxic Materials

PHENIX has made a conscientious effort to avoid the use of hazardous or toxic materials wherever practical. In cases where it was necessary to use toxic/hazardous materials like lead in the EMCal modules or beryllium for the beam pipe, procedures have been developed, documented and enforced to minimize exposure of personnel to toxic or hazardous materials and satisfy or exceed the requirements of all federal and state laws, regulations and orders.

1.7 Radiation Hazards

The only radiation hazard is a consequence of the operation of the RHIC accelerator. Radiation is produced by the interaction of the high energy ions or protons with the accelerator and/or detector components. Radiation exposures to personnel will be controlled using access control procedures, radiation surveys, radiation shielding, radiation interlocks and personnel training. Brookhaven uses the As-Low-As-Reasonably-Achievable (ALARA) principle in guiding its radiation control program and it will guide such efforts in regards to the PHENIX experiment.

The radiation hazards encountered at PHENIX are similar to those encountered in other experiments at BNL using high energy particle beams. The design of shielding at PHENIX as well as radiation interlocks and access control will be done in accordance with the BNL Radiological Control Manual and the RHIC Design Criteria for Prompt Radiation.

1.8 Training Requirements

The training plan for the Project will address, environment, safety and health requirements in accordance with criteria specified in RHIC OPM 5.7.0.0 ES&H Training. Visitors and staff receive formal training as appropriate for their work assignments.

1.9 Design Basis Accident and Failure Modes and Effects Analysis (to be inputted upon completion of these documents). For details, see Section 2.3.2.6 and Appendices 29 and 30, respectively.

1.10 Applicable Safety Codes and Standards

1.10.1 Introduction

The analysis of the PEHNIX detector, along with its supporting documentation, demonstrates that the PHENIX detector conforms to the applicable criteria in the BNL ES&H Manual, Radiological Control Manual, RHIC Project OPM, applicable national design or safety codes, and Department of Energy Orders shown in Table 1-A-2. Conformance with these standards will reduce the potential for an incident such that no more than minor on-site and negligible off-site impacts to people or the environment are possible.

1.10.2 Design Reviews

Designs, fabrication, installation, and test of experimental detector systems and ancillary support systems have been subject to internal design reviews. The design review teams have been comprised of competent panels, appropriate to the particular system and/or subsystems under review. Additionally a standing RHIC Experimental Safety Committee, Radiation Safety Committee, Laboratory Electrical Safety Committee or specifically charged sub-committees, appointed by RHIC and BNL management, have reviewed various aspect of the detector.

2.0 PHENIX

The following sections describe the elements of the PHENIX experiment including the three large magnets and the array of detector systems.

2.1 PHENIX Magnets and Magnet Return Steel

Two magnet systems, the central magnet (CM) and magnets for the north and south muon arms, muon magnet north (MMN) and muon magnet south (MMS) comprise the PHENIX magnet subsystem. Figure 4-P-1 shows a view of the central and muon magnets.

2.1.1 The Central Magnet and Magnet Return Steel

The CM shown in Figure 4-P-2 is an axial field magnet energized by a pair of concentric coils installed in co-linear steel pole faces. The magnet provides a uniform axial magnetic field of about 4750 gauss.

Power for the CM is provided by a 900 kW (2000 Adc, 450 Vdc) power supply.

2.1.2 Muon Magnet and Magnet Return Steel (North and South Arms)

The muon magnets (MMN and MMS) (shown in Figures 4-P-3 and 4-P-4) consist of two double layered coils wound on cylindrical flats on a large tapered iron piston.

2.1.3 Safety Assessment of the Magnet Systems

The PHENIX Magnet System is characterized by (1) high currents, (2) multiple power feeds with complex interconnections, (3) significant amounts of stored energy, and (4) magnetic field hazards. The following discussion focuses on what is needed to ensure compliance with safety standards and also focuses on design features which have been incorporated in order to reduce the risk of damage to equipment and injury to personnel.

To mitigate safety hazards associated with the CM and its power supply, the following equipment safety features have been incorporated into the power supply system:

(1) Interlocks on the cooling water return lines to shut power down in the event water flow is lost.

(2) A lockable, fused disconnect switch.

(3) Fuses very close to the maximum input power.

(4) Output cables power ratings de-rated to meet the National Electrical Code (NEC).

(5) Input power, control and interlock cabling complying with the NEC.

Power supply specifications also include: (1) a single power feed (480 Vac), (2) a grounding pad for connecting facility safety ground, (3) fail safe interlocks, (4) all interlocks latching, requiring a manual reset to assert “on,” (5) an Emergency Shutdown Button (works in local or remote mode), (6) interlocking access doors, (7) compartmentalization, (8) galvanic isolation on all control and interlock inputs, and (9) temperature and water flow interlocks for each cooling circuit within the power supplies.

Interlocks will also be put on the following external magnet features. Power supplies will be interlocked to the magnet coils via: (1) switches on all safety access covers over terminations, (2) temperature switches on coil conductors and as previously mentioned , (3) on cooling water return lines. Provision will be made for interlocking the power supply to a detector area key switch. Diagnostic monitoring for external interlocks on the CM outer coils is provided.

To mitigate potential electrical hazards and reduce risks to personnel, suitable barriers between personnel and energized conductors were constructed and strict adherence to lockout/tagout procedures are required and enforced when working on the magnet sub-system. Central to ensuring magnet safety are the specific operating and maintenance procedures and a fully documented training system for all personnel authorized to work on the magnet or its power systems. To further enhance power supply safety, standard industrial AC protection and multiple level DC protection, including interlocks, are installed. Power supplies and conductors are not accessible to personnel and are enclosed in locked and tagged enclosures. All power supplies have suitable over-current and over-voltage protection and discharge circuitry. Conductors are sized so that they are not exposed to power beyond their design limits as required by the RHIC OPM (Section.5.1.5.0.1) and BNL ES&HM (Section.1.5.2). Ground fault detection and interlocks are in place. It is unlikely that any maintenance would require working “hot” and such work will not normally be authorized. If it is required, an appropriate justification for such work must be generated and be reviewed by competent and knowledgeable authorities as required RHIC OPMs 5.0.2.2 and 10.1 or 10.2, as appropriate.

Loss of cooling water to the magnet coils is a potential hazard and one that could cause significant equipment damage and program interruption. Loss of cooling has been mitigated by the use of temperature, flow and buss resistance interlocks, and direct water leak detection by water mats. These systems initiate an emergency shutdown of the appropriate magnet power supplies in the event of an interlock.

Fire detection systems and fire suppression systems for magnet and power supplies, are provided.

The magnet and magnet power supplies use a significant level of security to prevent unauthorized access to systems controlling the magnet. Key components like the magnet power supplies are located in a restricted access area. Security has been implemented in the computer control system to prevent unauthorized operation or changes in magnet status or state. All interlocks are periodically tested and all major connections will be periodically inspected.

2.1.3.1 Magnet Controls and Interlocks

The PHENIX magnet interlock and control system is comprised of two distinct parts:

- Each power supply contains a magnet interlock controller. The power supply interlock controllers are hard wired to the Klixons, flow switches, crash switches, and key switches.
- A PLC is located in Building 1008B. The PLC monitors the thermistors, voltage taps, and miscellaneous interlocks and alarms. The PLC interlocks a power supply through its interlock controller. The PLC can be controlled and monitored from the PHENIX Counting House.
- A PC located in the PHENIX Counting House provides the control function. A RS422 cable from the PC to each power supply provides two-way communication. The PC can monitor and control each power supply.

2.1.3.2 Safety Assessment

The PHENIX CM produces an axial magnetic field which is 10^4 Gauss (1 Tesla) at the vertex (collision point) and which decreases to less than 500 Gauss (0.05 Tesla) at a radial distance of approximately 250 cm. There are three requirements for safeguarding of personnel against magnetic hazards, as specified in DOE 5480.4 "Environmental Protection, Safety and Health Protection Standards" which requires compliance with the American Conference of Governmental Industrial Hygienists publication “Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices:”

1. Routine occupational exposures should not exceed 600 Gauss (0.06 Tesla) whole body or 6x 10^3 Gauss (0.6 Tesla) to the extremities on a daily, time-weighted average basis.
2. Workers having implanted cardiac pacemakers should not be exposed above 5 Gauss (0.0005 Tesla).
3. Ferrous objects should be prohibited or shall be used in a fashion which prevent them from being a hazard.

Ferrous objects are prohibited from the high field region when the magnet is on. Barriers are used to prevent casual access to the area. Measurements show the field to be low (<0.05 Tesla (<500 Gauss) near the yokes falling off rapidly with distance) outside the return yoke. Appropriate barriers and signs are used to prevent accidental exposure to fields above the limits.

During normal operation, when the magnet is in the collision hall, the magnetic field hazards to personnel shall be mitigated by the combination of barriers, warning signs and administrative procedures. The supervised access training will warn about the magnetic field hazards listed above, prohibit entry to persons with surgical implants and pacemakers, and specify that entry inside the roped off area requires additional permission from PHENIX management. These precautions effectively eliminate the hazards generated by the rather low (fringe) fields of the PHENIX magnet and should guarantee that the magnetic field hazard is low. Note that, in contrast to the Central Magnet, the PHENIX Muon Magnets produce a radial magnetic field which is largely confined to the space between the magnet piston and the flux return plates or lampshade.

The Muon Magnets (with detectors inside) constitute a “Confined Space” hazard. Personnel will not be allowed to enter the magnets once the detectors are installed, unless at least one or more of the lampshade panels are removed. Prior to working inside a magnet, a Confined Space Entry Permit shall be issued.

2.2 PHENIX Detectors

2.2.1 Overview

Section 2.2 provides a detailed description of the detectors for the purpose of identifying design or operational features that have an impact on safety. For each case, a specific Hazard

Assessment is given. Section 2.3 contains description of the systems and services common to all detectors along with hazard assessments. The PHENIX Design Basis Accident (DBA) is discussed in section 2.3.2.6 and Appendix 28.

2.2.2 Inner Detectors

The PHENIX experiment has a set of detectors located close to and around the beam pipe. The first of these inner detectors, the Multiplicity and Vertex Detector (MVD) is a silicon detection sub-system comprised of silicon strips and pads housed in a low density frame that surrounds the beam pipe over the collision point. The other inner detector, the Beam-Beam counter (BB) consists of 2 units placed around the beampipe just downstream of the CM pole in both directions. These are photomultiplier tube based Cherenkov radiator arrays to detect forward-scattered, charged particles.

2.2.2.1 The Multiplicity and Vertex Detector (MVD)

The MVD is composed of two parts: two end caps and two concentric central barrels. The central barrels are thin plate-like semiconductor grade silicon wafers. The end caps are constructed from truncated wedge shaped wafers arrayed to form a disk. The wafers contain thousands of semiconductor diodes which are biased at voltages not exceeding 100 V. The front-end electronics (FEE) is optimized for minimum size, power dissipation and cost.

The half cylinders are covered along their inner and outer diameters by a tight aluminized Mylar foil to electrically isolate the MVD and maintain temperature and humidity.

The MVD is light enough for 2 people to carry and install it in place. Its clam shell design allows for removal/installation after the beam pipe is in place. A commercial scissors-type personnel lift table, permanently bolted to the lower yoke of the CM, will be used to access the MVD.

About 450W is dissipated inside the MVD enclosure. Temperature sensors from all MCMs and motherboards are constantly monitored for alarm conditions as a part of ancillary control system. All power supply lines coming into the MVD enclosures are fused in addition to being voltage and current-limited to avoid any possible overheating of components. The power supply units inside the MVD rack are also current and voltage limited.

The MVD rack (containing power supplies, interface modules, G-Links and ARCNet) is supplied to MVD as a PHENIX standard. This rack will reside outside the MVD enclosure. The racks are located away from the subsystem, mounted directly on the Central Magnet. The smoke, fire and liquid hazards inside the MVD rack are detected, alarmed and power-interlocked. The majority of cables, other than power, between the MVD rack and the MVD enclosure consists of pleated, foil-shielded 3M ribbon cables with NEC 725, CL2 flammability rating. The connectors used are similarly rated. The 18AWG power cables are also rated for flammability. The silicon bias voltage, which will stay less than 60V for the lifetime of the detectors, is also current limited at 120uA per detector, and routed through individual cable connections; not shared. Any failure in one supply line does not affect the operation of the others. All connections at the MVD enclosure are made in the one-inch clearances between the end plates and the magnet nose cones, forming conduits for all cabling.

2.2.2.2 The Beam Beam Counters (BBC)

The Beam-Beam Counter (BB) system consists of 2 assemblies. Each comprises an array of 64 Cherenkov counters surrounding the beam pipe just outside the central magnet poles. All high voltage, signal and ground cables will connect to the outside through specially designed FR4 patch panels. The high voltage will be supplied to the tubes in groups of 8 through SHV connectors. Calibration is supplied by the PHENIX common laser located in the counting house through fiber optic cables. The heat load is removed by a flow of nitrogen gas. Temperature will be monitored inside the canister and interlocked to the high voltage.

The BB FEE and LVL-1 trigger electronics as well as other DAQ components are located in standard PHENIX racks mounted on the side of the lower return yoke of CM.

2.2.2.3 Inner Detectors - Specific Hazard Assessment

The location of the MVD places it in the axial magnetic field generated by the Central magnet and in an inaccessible region when the detector arms are in position to take data.

The most significant safety issue unique to the MVD concerns personnel safety and the risk of damage to other PHENIX detectors and the beam pipe while accessing or installing the MVD. The MVD is located some 15 ft above the floor and will utilize a scissors-type personnel platform for servicing. This platform will have railing and guards as required by OSHA for such scaffolding and elevated work platforms.

MVD installation, alignment or servicing poses a hazard to the beam pipe which has thin walls. This hazard has been reduced by using a written procedure for installation and removal. There will be no maintenance of the detector once installed. The MVD is removed to an outside clean room area for any maintenance. In addition, precision fixtures will be designed to maintain separation of the MVD and the beam pipe. All personnel working in close proximity to the beam pipe or with the MVD will be properly trained and supervised. The MVD cable plant is designed so that no cables hang above the beam pipe or the MVD so there will be no chance that the cable will strike the beam pipe or be pinched by the MVD when the clam shell is closed.

Location of the MVD in the Central Magnet's field poses hazards to personnel who could be exposed to a high magnetic field in excess of DOE specified limits. (See Section 2.2.1, pertaining to the Central Magnet and the possible magnetization of support structures.) The MVD is made of non-magnetic materials and poses no magnetization hazard. MVD SOPs will require a tool count and require the use of non-magnetic tools. MVD personnel will be trained in magnetic hazards and supervised when working on the MVD. PHENIX magnets will be de-energized and their power supplies locked-and- tagged out during MVD installation, alignment and maintenance.

The detector is made of flammable materials and although the electrical supplies are neither high voltage or high current as defined by the RHIC OPM 5.1.5.0.1 and NFPA-70 (NEC), there is a risk of fire and or smoke hazards in the event of electrical malfunction. There will be a global fire detection system for PHENIX and appropriate smoke or temperature detection systems will be provided to detect fire or smoke conditions in the MVD and provide an appropriate response. The flammability of MVD materials has been studied and the least flammable materials or materials less likely to produce toxic or corrosive gasses upon heating, charring or burning were chosen. The MVD support structures will be made using Rohacell. Rohacell burns with a slightly smoky flame but generates no corrosive decomposition products.

Liquid and air cooling will be used to reduce the MVD heat load. The hazard posed by coolant spillage within the MVD will be mitigated by building a leakless system. The liquid used is FC-17; this electrolytic fluid does not cause electrical shorts.

2.2.3 Tracking System

PHENIX's tracking system in each carriage consists of a gas filled, multi-wire drift chamber (DC), three cathode pad chambers (PC1, PC2, PC3) and in the East arm only, a Time Expansion Chamber (TEC). Technological similarities between the tracking chambers and their close proximity to each other suggest common hazards and they are grouped together for the purpose of safety analysis.

2.2.3.1 The Drift Chambers

There are 2 drift chambers, one in each carriage located immediately outside the magnet pole circumference. Each drift chamber is one continuous gas volume and mechanical structure that spans a length of 2 meters along the beam axis and 40cm deep. Welded titanium arcs and end-beams, braced by internal gussets, provide the mechanical frame

The drift chambers are filled with $3m^3$ of argon-ethane (50-50) mixture. The anticipated flow rates are 5 l/min for normal operations and 20 l/min during purge and flushing operations. The chambers will have a 10% collapsible buffer volume to guard against changes in atmospheric pressures. The windows are single-piece, seamless 5mil aluminized Mylar.

2.2.3.2 The Pad Chambers (PC1, PC2 and PC3)

The Pad Chamber (PC) system is comprised of three multiwire gas chambers (PC1, PC2 and PC3) in each central arm. PC1 consists of 8 panels which located between the DC, and the RICH counter. These are mounted on the DC frame and the two are installed together. On the East carriage PC2 and PC3 are mounted to the front and back of the TEC. This assembly is located between the RICH and the TOF (lower 2 sectors), and EMCal (upper 2 sectors). On the West carriage PC2 and PC3 are supported by their own frame in the same location. PC2 and PC3 each consist of 8 chambers - 2 in each sector on either side of the mid-plane. The 3 chambers use a similar construction using an S2 glass frame. The chamber is a honeycomb sandwich construction of 2 Hexcel layers that are glued to S2 boards. The pixel cathode pads are etched on one side and the readout printed circuit on the other.

Gas will flow in the region between the cathodes. The gas is a 50-50 mixture of argon-ethane at atmospheric pressure.

The preamp and discriminator cards for the readout are on the outside face of each chamber, and are connected to the FEE cards mounted along the sides.

2.2.3.3 Time Expansion Chamber (TEC)

The PHENIX Time Expansion Chamber (TEC/TRD) system consists of sets of tracking and transition radiation planes that occupy the space on the East carriage between the PC2 and PC3 chambers. The approximate dimensions of each plane is 3.5 m x 1.7 m. These planes are grouped into 4 sectors of six planes each to cover 90 degrees in azimuth. The TEC will use 90% argon and 10% methane operating slightly above atmospheric pressure. The gas windows on individual planes are copper-clad Mylar. These plane are protected and backed on the outer edges by the stiff honeycomb structure of the PC.

High voltage lines are present on the anode boards at each end of the TEC planes along with surface mount RC components, coated with Hysol, to form an AC coupling from the signal wires to the amplifier shaper components. All components used, with the exception of the custom made ASICs, are either UL rated or follow industry approved standards. Cable runs from the amplifier boards to the FEM are bundled in Teflon coated jackets on aluminum supports at the edges of the chambers.

2.2.3.4 Tracking System - Specific Hazard Assessment

Device specific safety issues for the tracking system detectors include: (1) structural integrity of the tracking chambers, (2) the potential for fire due to the use of flammable gases and combustible materials (see Section 2.3), (3) hazards posed by working in close proximity to the central magnet (CM) (see Section 2.1.3), (4) risk of damage to fragile detector structures, (5) hazards associated with handling bulky detector modules, and (6) hazards associated with the use of high voltages.

The tracking chambers pose special problems with respect to flammable gas safety. Tracking chambers by design, contain un-insulated wires carrying high voltages and thus detection of minute quantities of oxygen is a high priority. In addition, these chambers have thin windows, walls and multiple penetrations for voltages and signals. A monitoring system is installed to verify that leaks remain acceptably small and that no pockets of flammable gas collect outside of the chamber volumes.

The need to minimize the thickness of detector window and chamber thickness leads to a situation where the detectors are especially fragile and susceptible to damage (i.e. perforation by sharp objects). All personnel working with or in close proximity to the chambers are to be trained, supervised and knowledgeable about the hazards present when working in close proximity to the detectors. Activities will be designed to minimize contact with the chambers and tool counts will be used to eliminate a hazard posed by lost hardware and tools. The risks are minimized by developing and implementing written procedures while working around central arms.

2.2.4 Ring Imaging Cherenkov (RICH) Detector

The Ring-Imaging Cherenkov (RICH) detector system serves as one of the primary devices for the identification of electrons. The RICH is located between the DC/PC1 and PC2 in each of the central arms. The RICH interior is filled with a Cherenkov radiator gas (usually ethane, but sometimes CO_2). The Cherenkov photons generated by electrons, positrons, and high momentum hadrons are reflected by spherical mirrors, and the photons are focused onto photon detectors which are high multiplicity arrays of photomultiplier tubes (PMT) grouped into supermodules.

The aluminum vessel is approximately 20 x 20 x 8 ft^3 with a gas volume of 40 m^3. The front and back windows (8.4 and 22 m^2 in area respectively) are made of 5 mils seamed kapton that are supported by graphite epoxy bars to minimize the deflection under gas pressure. Additionally a 3mil fire-retardant vinyl sheet is also used as a light shield. The mirrors are made of a carbon fiber epoxy composite with Rohacell cores. The mirror support structure is also Rohacell filled graphite-epoxy, and the hardware for attaching mirrors to the support structure is Delrin.

The phototube assembly generates about 1 kW per arm. The phototubes are mounted on a water cooled plate.

The process gas is pure ethane supplied via a single pass system at a pressure of 1/2" of water, as regulated by a bubbler, and vented to the LCVS. Two levels of passive overpressure protection are provided via a relief valve and/or a burst disk to the high capacity vent system. A buffer volume compensates for atmospheric pressure variations. An emergency purge with CO2 will inert the RICH contents in 4 to 5 hours.

The RICH has internal oxygen monitors which will detect excessive oxygen levels (in the range of 100 ppm up to 20% full scale) and provide early warning. Detection of levels at or above 5000 ppm of oxygen will shut the ethane supply and automatically initiate an emergency purge.

Flammable gas sensing will also be installed at the outside of the RICH vessels and interlocked to potential internal and external ignition sources. The external flammable gas sensors will also be interlocked to initiate emergency purge of the RICH.

The kapton windows on either side of the RICH are protected from projectiles by a vinyl barrier which isolates it from the electronics of the PAD chambers. The kapton/vinyl gap is continuously purged with nitrogen to inert potential ethane leaks.

The RICH detector has safety hazards in the areas of: (1) explosion potential given the use of ethane in significant quantities at or slightly above atmospheric pressure, (2) flammability (extensive use of flammable materials (carbon fiber, plastics, epoxies etc, and (3) mechanical safety issues including working in close proximity to the central magnet and other PHENIX detectors. The ignition of the ethane in the RICH forms the basis of the DBA discussed in Section 2.3.2.6.

The flammability of RICH materials was studied and the least flammable materials or materials less likely to produce toxic or corrosive gasses upon heating, charring or burning were chosen where possible. The PMTs normally operate in a pure CO_2 or ethane atmosphere where they do not constitute a hazard. However, there is a danger during initial purge of air or in the event of a substantial violation of the vessel integrity. Therefore, highly reliable monitoring of internal oxygen levels interlocked to PMT high voltage is a requirement.

The RICH is sandwiched between the PC1 and PC2 detectors of the tracking system. These adjacent detectors and the RICH windows themselves, could sustain damage during installation, adjustment or servicing by careless or improper handing of the RICH or tools used during the work. These risks are minimized by providing adequate supervision to those working with the RICH and adjacent detectors.

2.2.5 The Time-of-Flight (TOF) System

2.2.5.1 Description

The Time Of Flight Subsystem consists of a total of 10 flat panels of scintillator slats each of which is viewed with a photo tube and base attached to each end. The TOF is located between the PC3 and the lead glass calorimeter and occupies one sector (385 cm x 200 cm) and part of a second sector (100 cm x 200 cm) in the East central arm.

As material thickness and radiation length is a premium, each panel is constructed with commercial grade NOMEX honeycomb material bonded with epoxy impregnated graphite to form a backing. An aluminum frame forms the boundary of each panel.

The photo tube bases are held in an ABS plastic material. Pieces of the NOMEX and ABS material were subjected to flammability tests by ESHSD. The NOMEX material did not ignite under tests and thus is not considered highly flammable.

Polymide plastic frames are used for cable support. This represents a small amount and is considered acceptable.

The detector uses a the PHENIX same remote class IV YAG laser for calibration as the TOF and EMCAL systems. The fiber optic cable rating complies with the RHIC OPM 5.1.5.0.1. Two bundles will distribute the calibration signals to the detector, one outside and the other inside the panels.

The total power dissipation in the PMT bases is 2 kW. An array of cooling fans at each side of the detector remove this heat. Temperature monitoring is interlocked to the power supplies.

The signal and high voltage cables have acceptable fire rating for this location. The CAEN high voltage supply allows setting current limits to groups of 24 PMT bases at a time. Should one of those bases exceed the limit, all 24 channels are turned off.

2.2.5.2 Time-of-Flight Detector - Specific Hazard Assessment

The major safety issues concerning the TOF system are: (1) fire loading due to the use of Bicron 404 (polyvinyltoulene) scintillator material, and (2) mechanical issues involving TOF installation or servicing.

The TOF contains flammable materials in significant quantities. These are required to achieve the specified physics performance. They are the foam (honeycomb) material chosen for the TOF support structure, and the polymer scintillator material which is combustible and decomposes into toxic gases when heated above 300°C (The plastic softens at 70°C). The scintillator material is enclosed in a light tight aluminized Mylar wrapping with the photomultiplier tubes. An HSSD system mitigates the flammability concerns of the TOF.

The TOF PMT power supplies will have systems designed to detect electrical failures and shut down the electrical circuits if shorting or grounding is detected. The region between the TOF and the lead glass is protected by the HSSD system described earlier and a fire suppression system.

The TOF is sandwiched between the EMcal and the PC3 of the Tracking system. The TOF or the adjacent detectors could receive damage during installation, adjustment, or servicing by careless or improper handing of the TOF or tools. These risks will be minimized by developing and implementing procedures while working around the central arm and by providing adequate supervision to those working with the TOF.

2.2.6 Electromagnetic Calorimeters (EMCals)

2.2.6.1 Description

The EMCal is the outermost detector in each central arm. The West carriage contains four sectors of lead-scintillator (PbSc) while the East carriage has lead-glass in the lower two sectors and lead-scintillator in the upper two. The entire calorimeter is read out with phototubes .

The PbSc EMCal towers will consist of stacks of plastic scintillator tiles sandwiched between sheets of paper and lead plates. The plastic tiles will be made from a dry mixture of polystyrene and two wave shifting colorants (1.5% p-terphenyl and 0.5% POPOP). A laser will be used to calibrate the PbSc EMCal PMTs. Laser radiation will be distributed using clear UV transmitting optical fiber, sent also to the BB and TOF. The laser used for PbSc EMCal calibration will be the PHENIX YAG unit described in Section 2.3.3.

2.2.6.2 Electromagnetic Calorimeters (EMCals) - Specific Hazard Assessment

The PHENIX EMCal systems pose the following safety concerns: (1) potential fire hazard due to the use of flammable materials (e.g. polystyrene scintillator tiles and cable insulation) , (2) risk of personnel injury due to the weight of EMCal components which may shift during material handling, and (4) a risk of exposure to toxic lead.

The polymer scintillator tiles used in the PbSc EMCal are considered a combustible material. In case of the scintillator tiles, the fire hazard is considered mitigated by the isolation of the tiles in light-tight stainless steel boxes and by their separation from each other by heat absorbing lead plates. The degree of isolation limits the access of oxygen to support combustion and the lead acts as a heat sink raising the amount of heat needed to bring the temperature of the scintillator material to the ignition point. No credible energy source exists in or near the EMCals to generate the large amounts of heat needed to ignite the tiles. It is also unlikely that a failure involving fire in an adjacent PHENIX sub-systems would generate enough heat to pose a combustion hazard for the PbSc.

While there is lead in EMCal modules, it is totally contained inside a metal enclosure which effectively reduces the exposure to zero.

2.2.7 Muon Arms (North and South)

The PHENIX Muon system is comprised of two arms, arranged around the beam pipe to the North and south of the CM and the central arms. Each muon arm consists of a muon magnet(MMN ans MMS) containing the Muon Tracking systems (MuTr), and the muon identifier steel containing the Muon Identifier (MuID) detectors. The two magnets are described in Section 2.1.2. Each arm of the MuTr comprises three stations of tracking chambers, with three cathode strip chambers each. Station 1 is mounted on the upstream face of the magnet, and stations 2 and 3 are mounted inside. The MuID system comprises six walls of steel absorber interleaved with 5 sets of Muon Identifier panels hung in the gaps between the plates. The first absorber wall is the steel end-plate flux return of the muon magnet.

2.2.7.1 Description of the North Muon Arm

The North and South MuTr Stations 1 and 3 are constructed using NOMEX honeycomb panels with FR-4 copper clad boards laminated to them. Those panels sandwich a stretched wire plane. This construction provides a strong structure and a certain degree of protection against accidental punctures and resulting gas leakage.

Physics constraints dictate that station 2 be built with minimal material to reduce multiple scattering. Consequently, that chamber is constructed using metalized copper Mylar foils and wires stretched on a thin aluminum frame. The MuTr utilizes a recirculating gas system with a mixture of Isobutane-CF_4.

The gas used in the detector is CO_2-Isobutane in a non-flammable mixture, in a single-pass configuration. Each muon identifier arm has a gas volume of 29 cubic meters. Normal operation will require a flow rate to assure one volume gas exchange per 24 hours. The tubes are rated to withstand 6 times normal over-pressure.

The operating voltage of the tubes with the above gas mixture is around 4300 volts and the expected current is about 1 microampere per tube. A LeCroy HV supply will be used that provides a maximum of 5000 Volts per channel at a maximum current of 200 microamperes. The tubes are electrically isolated from the aluminum panels and supports. The HV and signal cables go through isolated feeds. The high voltage is fed to individual tubes via a special connector. The connector is certified by the manufacturer to 10 kV with less than 10 nanoamperes of leakage current. The connector box is filled with araldite to mitigate potential current leakage in high humidity.

The muon Identifier Front-End Electronics has components that are mounted both inside of the panels and external to the detector. Inside the panels there are small pre-amplifier boards which amplify the raw signals from the tubes and send them out of the panel to the Front-End Modules (FEM's) in VME-style crates contained in standard PHENIX racks. The low-voltage power supplies will be mounted in the same racks. The Gas monitoring and control systems are mounted near the edge of the Muon ID steel.

2.2.7.2 Description of the South Muon Arm

The detector technology for the South Muon Arm's muon tracker and muon ID system is identical to the North Muon Arm's. The differences between the two systems are that the South magnet and MuTr chambers are smaller and the magnet is mounted on tracks to allow it to move to facilitate access to all systems for maintenance.

2.2.7.3 Muon Arms - Specific Hazard Assessment

Major safety concerns identified for the Muon Arms are (1) Gas flammability , 2) Personnel safety while accessing chambers or electronics in either the enclosed spaces of the magnets or at elevated locations, and (3) oxygen deficiency hazard when working in enclosed spaces.

The geometry of the magnets which enclose the Muon tracking chambers provides isolation of the chambers from the from the rest of the PHENIX experiment This mitigates the fire and explosion hazard presented by those detectors, as discussed specifically in the DBA. Analysis presented in Section 2.3.2.6.

2.2.8 On-Line Systems (Electronics)

The purpose of the PHENIX on-line system is to select and archive events of potential physics interest at a very high rate as dictated by the RHIC luminosity. PHENIX uses front-end electronics (FEE) which are integrated with each detector to do as much signal processing as possible on or near the physical volume of the detector. Data from the FEE is accepted or rejected by the Level-1 Trigger (LVL-1) system which begins the process of selecting data of potential physics interest. Working in conjunction with the DAQ system as a part of the on-line systems is an ancillary systems control which monitors detector status, magnet status and RHIC Collider status and logs data that is essential for further data analysis of accepted events. On-line computer systems provide PHENIX operators and users with information concerning. Collider status, detector performance and events meeting physics criteria.. By design, the On Line ancillary system has no safety control or monitoring functions. There are no additional hazards presented by these systems not covered by previous discussions.

2.3 Hazard Assessments for Common Systems and Services

Section 2.3 lists safety-related issues for the systems and services that support the PHENIX detectors and outlines suggested or required measures to reduce the hazards to acceptable levels.

2.3.1 Electrical Hazards

The usual hazards associated with electrical systems are fire hazards and electrical shock hazards. The unusual electrical hazards presented by detector sub-systems are hazards from High Voltage Systems (Section 2.3.1.1) used to bias detector elements or photomultiplier tubes and Low

Voltage, High Current Systems (Section 2.3.1.2) which include power distribution networks for front-end electronics and rack mounted on-line electronics. The PHENIX experiment makes use of large numbers of power distribution and signal cables and safety requirements for cabling is discussed in Section 2.3.1.3. Data acquisition requirements have motivated the choice of Fiber Optic links to transmit data and control signals from the detector to the on-line and trigger systems. The special requirements of fiber optic cabling are discussed in Section 2.3.1.4. A number of racks will be needed to house on-line system circuit boards and modules. Their requirements will be discussed in Section 2.3.1.5.

Low risk from electrical hazards will be achieved by compliance with BNL ES&H Standards 1.5.0,1.5.1 and 1.5.2 and the RHIC Project OPMs 5.1.5.0, 5.1.5.0.1 and 5.1.5.1. In particular, RHIC SEAPPMs adapt the generic guidelines to the environment found in an accelerator and particle physics facility. All standard AC power distribution adheres to codes set by the NEC.

2.3.1.1 High Voltage Systems

High voltage power supplies are used to bias photomultipliers (BB, RICH, TOF and EMCals), wire chambers (DC, pad chambers, TEC, Muon tracking chambers and the Muon ID chambers). High voltage systems present a significant hazard of electrical shock, can sometimes contain significant stored energy, and present an electrical sparking hazard in the presence of flammable gases.

High voltage conductors and wires will be shielded from direct contact with personnel. For high voltage systems up to 5 kVDC, RHIC OPM 5.1.5.0.1 requires the following features. Connectors for high voltage shall be incompatible with connectors for signal cables. Only components and cable properly rated for the intended application shall be used. Red-jacketed cable is used for high voltage applications with a single exception of multi conductor "Si HV" wire, which has been approved. To eliminate the possibility of cable fires caused by high voltage, high voltage is to be distributed by cables utilizing a fully surrounded grounded braid or shield. The RHIC OPM 5.1.5.0.1 specifies "SHV" connectors for use in high voltage applications of less than 5kV. PHENIX also uses approved "LHV" and "AMP" connectors for specific applications. Programmable high voltage supplies can deliver lethal electrical shocks, and PHENIX will comply with RHIC OPMs 5.1.5.1 and 5.1.5.0.1 which list required measures for such power supplies.

To decrease fire hazards from equipment failure, all high voltage power supplies will have input circuit protection as well as output current limiting protection. The high voltage systems will be interlocked with flammable gas monitoring systems. In the event of a flammable gas alarm, power will be automatically shut off to all high voltage systems.

All supplies are commercially purchased from either LeCroy Systems or CAEN and will all be tested before use including control and fault conditions. Remote sensing and control is via Arcnet. All supplies are current limited and voltage limited in modules, and interlocked to detectors. Supplies will be thermal overload protected and thermally monitored, and all crate mains and all internal supplies are fused. HV supplies will be provided with suitable LOTO and all personnel involved in the installation and operation of these supplies will receive training in the use of LOTO procedures.

2.3.1.2 Low Voltage, High Current Systems

This class of electrical system is characterized by low voltages (typically 15 V, with some 48V) but because of high currents presents a significant risk of fire or thermal damage. RHIC OPM 5.1.5.0.1 sets the requirements for such circuits. Low voltage high current power systems used in the FEE, DAQ and LVL-1 Trigger systems that pertain to the tracking systems comply with guidelines laid out in the NFPA-70, BNL ES&H Manual 1.5 and RHIC OPM 5.1.5.0.1. All personnel involved in the installation and operation of tracking system components will receive training in the use of electrical systems as required by BNL and the RHIC Departments.

Selection of materials for electrical systems (i.e. wire insulation, terminal blocks, barriers etc.) will be on the basis of compliance with Underwriters Laboratory (UL) # 83 which provides standards for flame spread, smoke toxicity etc. Connections between cables and power supplies or loads will be clearly labeled and polarized so as to prevent any possibility of misconnection or shorting.

All power supplies used on the detector are required to be of a type that have over-voltage and over-current protection and have their AC inputs to the primary fused to avoid fire because of equipment failure. This equipment will be powered down if an alarm occurs from the flammable gas monitoring system or if the supply temperature exceeds limits to be determined.

The LV system is a plug-in board style. All power supply inputs are fused. All supply outputs are current limited. There is a window monitor of output voltages, with remote and auto fault shutdown capability which is interlocked to detectors. All LV cabling is per RHIC safety standards (minimum of VW-1 rating and maximum fault current of 80% cable current rating). All supplies are thermal protected and monitored.

2.3.1.3 Cabling

The primary hazard presented by cabling is fires in cable tray systems. While high intensity fires are improbable, most of the damage would be caused by corrosive gases released from insulating materials during the early stages of polymer degradation. Cable types used on the PHENIX detector and in cable trays will be types that provide maximum resistance to flame spread.

The NEC (NFPA-70) requirements also include sizing conductors to carry the load current under all anticipated load conditions. If an electrical fault does occur, the cables will be designed with sufficient margins to support the current necessary to cause a trip of the fusing without overheating or damage to the conductors or insulation. The conductors will also be sized to safely support the fault current until the operators or other automatic systems can shutdown the power supply.

The signal cabling will conform to the standards outlined in Section 5.1.5.0.1 of the RHIC Project OPM. Copper signal cables, co-axial cables and multi-conductor signal cables that do not carry significant current or voltage will be restricted to the type of general purpose communications cables that are permitted as per RHIC OPM 5.1.5.0.1.

All detector cabling is CL2 rated and approved with very few exceptions (TEC, lead glass, and TOF).

2.3.1.4 Fiber Optical Systems

The safety requirements for low voltage systems are applicable to the interfaces between fiber optical and electronic systems. While not at risk from the signals they contain, fiber optic cables may be at risk of thermal damage from electrical cables placed in close proximity. The NEC requires that signal, control and power cables in trays be separated by appropriate barriers.

2.3.1.5 Racks

Racks will be placed on the detector carriages, near the base of the central magnet and in the counting house to house power supplies, readout electronics and other support electronics. The racks located in the PEH are fully enclosed NEMA 12 rated, operate at a positive pressure, and are NEC approved for class1-division2. They are cooled by vertical forced air with water cooled heat exchangers. Each rack frame is fully grounded. All racks in the PEH contain rack monitor systems that include smoke detection, over-temperature sensors, voltage monitoring, with automatic and manual local and remote trip for rack AC power. All racks that house equipment used to supply primary DC power to detector components (HV or Low Voltage) will be interlocked with the flammable gas monitoring system. The racks will be shut down if the ambient temperature exceeds limits to be determined or if the fire detection system signals an alarm.

2.3.2 PHENIX Gas Systems

2.3.2.1 Introduction

PHENIX has several detector systems that use gas mixtures and in some cases pure gases (inert and flammable) at atmospheric pressure. These gases include: argon, carbon-dioxide, carbon-tetraflouride, ethane, helium, isobutane, methane, neon, nitrogen and xenon. A block diagram of the PHENIX Gas Systems is shown in Figure 4-P-6. These gas systems occupy four main areas of the 1008 complex. These are the Gas Storage Shed (2.2.7), the Mixing House (2.2.8), the Interaction Region (IR with detector chambers) and the Vent Stacks (2.2.9), and the pipe based transport systems between them. The largest inventory of gases is stored in the Gas Shed in cryogenic liquid storage tanks or compressed gas storage cylinders. A plan view of the1008 PEH and vicinity is given in Figure 3-U-2.

PHENIX detector gas systems are either recirculating or single-pass (venting), and have dynamic pressure control. In a number of detectors substantial quantities of gases at atmospheric pressure, including flammables, are contained in thin windowed vessels. These vessels consist of a structurally sound framework with polymeric walls of materials such as Mylar, Kapton, Aclar or PVC with single layer thickness from a few mils up to a millimeter. It is anticipated that the normal leak rates (including diffusion) from all detectors will be less than 1 scfh of flammable components.

Breaches in containment (fractured pipes, ruptured windows, excessive leaks at joints, seals or feed-throughs) would be caused internally by improper pressure regulation combined with failure of multiple overpressure/underpressure protection devices. Externally, breaches might be caused by mishandling (crushing, piercing). High voltage electronics reside on the periphery and even within detector chambers. The nature of the experiment poses some significant challenges in the areas of flammable gas safety and oxygen level monitoring.

2.3.2.2 Flammable Gas Hazard

Design criteria for experimental flammable gas systems are listed in the BNL ES&H (Section 4.11.0) and RHIC OPM (Section 5.4.11.0), and are adhered to by PHENIX. Another excellent guideline is the Flammable Gas Safety Code by the Director General of CERN the European Research Collaboration, Rev. G, November 1996. According to the latter, PHENIX Gas Systems are classified as Risk Class 3 in the Gas Storage and Interaction Region areas, while the Mixing House and Vent Stack areas are in Risk Class 2.

Tables 4-P-1 and 4-P-2 tabulate the flame and combustion properties of the flammable gas constituents used in PHENIX. Table 4-P-3 gives the volumes of combustible gas mixtures of detector chambers.

Table 4-P-1

Properties of Detector Gases Used in PHENIX

Gas	Symbol	Molecular Weight	Heat of Combustion (MJ/kg)*	
			MJ/kg	KJ/mol
Air		29	-	-
Nitrogen	N_2	28	-	-
Argon	Ar	40	-	-
Methane	CH_4	16	50.00	800
Ethane	C_2H_6	30	47.40	1422
Isobutane	C_4H_{10}	58	45.60	2645
Tetrafluoromethane	CF_4	88	-	-

* Energy released when burned with oxygen at standard temperature and pressure to form water vapor and carbon dioxide, source Baker et al., 1983.

Table 4-P-2

Flame Properties

Fuel	% Fuel in stoichio-metric air	Flame Temperature (K)	Minimum Ignition Energy (mJ)	Autoignition Temperature (K)	Flammability Limits (% fuel in air)	
					Lower	Upper
Ethane	5.7	2170	0.25	788	3.0	12.4
Isobutane	3.1	2170	0.26	678	1.8	8.4
Methane	9.5	223	0.28	713	5.0	15.0

Table 4-P-3

Combustible Gas Volume per Detector

Detector	Gas	Mix (by volume)	Volume (m^3)	Total PHENIX Volume (m^3)
Drift Chamber (DC)	Ar/C_2H_6	50/50	2.8	5.6
Pad Chambers (PC)	Ar/C_2H_6	50/50	0.56	1.12
Time Expansion Chamber (TEC)	Ar/CH_4	90/10	3.25 (East)	3.25
Ring Imaging Cherenkov Counter (RICH)	C_2H_6	100	40	80
Muon Tracker (MuTr)	CF_4/C_4H_{10}	50/50	1.46	2.92
Muon Identifier (MuId)	CO_2/C_4H_{10}	91/9	29	59
TOTAL				151.9

Initiation of fire or explosion requires definite proportions of fuel to oxygen as given by the flammable limits, and an available ignition source. The basic method for dealing with the hazard presented by flammable gases is to prevent the formation of explosive mixtures by controlling the former or, where possible, by eliminating the later condition. Central Tracking, Muon Tracking and Muon ID chambers, by design, contain un-insulated wires carrying high voltages (1000 V+).

Thus numerous precautions are taken to ensure the first condition cannot exist, or is otherwise detected and abated in short order. Precautions include: proper engineering practice (system design, component specification and installation, and facility design and construction); compliance with applicable codes; complete system safety analysis and testing; and comprehensive documentation for safety, operating procedures, training, and maintenance schedules. These are detailed in Section 2.3.2.5, Safe Design, Installation and Start-up of PHENIX Gas Systems.

Ignition sources are generally associated with electrical equipment including the detector electronics and associated power supplies. Power to these electronics and racks is interlocked with the flammable gas monitors. Detection of flammable gas levels at a lower limit signals a warning, while levels at 25% of the lower flammability limit sounds an evacuation alarm, closes flammable gas supply and initiates purge of detectors, as well as tripping electrical power. A similar response is invoked by oxygen levels in the detector chambers in excess of 500 ppm. Only limited and strictly controlled access to the IR is permitted when flammable gas is present in the detectors. Access to the Mixing House will also be limited.

2.3.2.3 Oxygen Deficiency Hazard

The combination of confined volumes of gas with either relatively large flow rates or large stored volumes creates a potential ODH hazard. The sum of all normal operating flows of non-air gases in the PHENIX detector is less than 500L/min. For a simultaneous emergency purge of all detectors with flammable gas it is less than 4000L/min with a duration of less than 5 hours. Additionally, continuous nitrogen purges of several enclosed spaces in the detector vent into the IR.

Normal gas flow rates and the nitrogen purges are balanced by the introduction of sufficient fresh air into the building. This is accomplished via a continuous fresh air intake to the IR HVAC system at a rate of at least 10 times the normal combined input rate. Supplemental air circulation is provided in areas where the potential for pooling would exist if lighter or heavier-than-air gases were permitted to stratify. Because the detectors operate at essentially atmospheric pressure, even a large leak will not spill gas at larger than the inlet flow rate for the detector involved. During any period of accelerated purge, personnel are excluded from the IR by procedure.

The PASS system includes a number of ODH monitors in the IR and local monitoring in the Mixing House. On detection of low oxygen levels, the emergency ventilation system is enabled, ODH alarms are sounded, and indication is sent to the MCR.

There are no ODH concerns associated with the cryogenic bulk storage, as all liquid phase piping remains outside of the building; likewise for the compressed gas storage. Vent stack gases are normally mixed with air from high flow fans before exhausting to the top of the berm. Other ODH precautions include system safety analysis and testing.

2.3.2.4 Compressed Gas and Cryogenic Hazards

PHENIX conforms to the design criteria for compressed gas cylinder safety and cryogenic liquid storage, usage and handling are listed in the BNL ES&H Standards 1.4.0 and 5.1.0 and RHIC OPMs 5.4.11.0 and 5.5.1.0.

Nitrogen and carbon-dioxide are stored as cryogenic liquids. Compressed inert gases carbon-tetraflouride, helium, neon and xenon are stored in cylinders. Separately the liquefied hydrocarbons, ethane, methane and isobutane, are stored in cylinders. Table 4-P-4 gives the total inventory (primarily in gas storage) of the constituents of PHENIX gas mixtures.

TABLE 4-P-4

Storage Inventory of the Constituents of PHENIX Gas Mixtures

Gas	Symbol	Phase	Volume (m^3 at STP)
Argon	Ar	Compressed Gas	170
Helium	He	Compressed Gas	6.91
Carbon-Tetraflouride	CF_4	Compressed Gas	120
Methane	CH_4	Compressed Gas	10
Ethane	C_2H_6	Liquefied Gas	450
Isobutane	iC_4H_{10}	Liquefied Gas	102
Carbon-dioxide	CO_2	Cryogenic Liquid	460
Nitrogen	N_2	Cryogenic Liquid	8800

Compressed gas cylinders present the hazards associated with pressure vessels: rupture, high pressure streams, and projectiles. Liquid storage presents the hazards associated with cryogenics:

burns, frostbite, and trapped volume. These are a consequence of the capacity of the liquid to absorb heat and its corresponding increase in pressure.

Gas cylinders and cryogenic storage tanks are re-certified every four years. Cylinders are visually inspected upon receipt. Cryogenic tank performance is logged and proper filling procedures are followed. Further safety precautions include: proper facility design and construction; compliance with applicable codes; and comprehensive documentation for safety, operating procedures and training, and maintenance schedules. These are detailed in the next section.

2.3.2.5 Safe Design, Installation and Start-up of PHENIX Gas Systems

The design of the PHENIX gas systems has proceeded along a careful course to ensure safety at all times. Particular consideration has been given to those safety concerns associated with the use of flammable gas, compressed gas, cryogenic and ODH hazards.

The system is designed to be capable of providing, as necessary: start-up purging of detector chamber and piping, internal oxygen level monitoring of detectors, flammable gas monitoring, supply/return flow rate comparison, vent stack gas dilution, and relief of trapped liquid volumes.

System components include a multiplicity of safety devices or require safety oriented specification, including: blow-down ports and purge “Tees” to assure gas purity, supply cylinder flow limiters, CGA connectors and flare type compression fittings on flammable gas lines, reinforced nylon tubing in protective sleeves, over-pressure/under-pressure protection, flammable gas compatibility, lock-out/tag-out of supply valves, seals with low leak rates, high purity gas filters, flash arrestors, check valves, and restrictive flow orifices.

Design of the system where applicable complies with the following applicable codes.

A. ASME B31.8: Gas Transmission and Distribution Piping Code.

B. ASME Boiler and Pressure Vessel Code: Section VIII.

C. Bureau of Mines: Bulletins 503 and 627, Flammable Gas Mixtures.

D. RHIC OPM.

E. NEC Elect Enclosure Art 500: Class I Div 2

Consideration is given to facility specific safety precautions. The Gas Storage Area includes: bollards, delimited storage, barrier separation of inert and flammable gases, and straps for cylinder racks. No permanent electrical power is required, only battery powered lighting will be used.

The Mixing House includes: National Fire Protection Agency (NFPA) compliant building materials, doors, windows, electrical enclosures, and frangible panel explosion venting; electrical components rated for NEC Class I Division 2; Flammable gas/ fire/oxygen deficiency hazard monitoring; safe utility services including: hot water heat, sufficient HVAC ventilation, underground power lines, uninterruptible or diesel generated back-up power; and lighted, uninhibited exits.

The Interaction Region, where the detectors reside, contains a variety of safety systems which are discussed in detail in the Safety Analysis Section 2.2.5. The main Safety Systems include fire, smoke, flammable gas and oxygen deficiency monitors. Some of these exist at up to three levels (e.g., smoke). At the detector level there exists independent temperature, flammable gas, and/or chamber oxygen monitoring. Sufficient circulation is created in cavities which offer the potential for pooled accumulations of heavier-than-air gases. The Interaction Region is serviced by an HVAC system which provides a continual fresh-air exchange rate of 1500 CFM, averting rising concentrations of leaked and locally vented gases. IR gas system flows will be interlocked with the HVAC system. In the Emergency IR Vent System mode, a high flow fan circulates 37,000 CFM through the same duct work to dilute the IR and vent sudden, large gas leaks. This mode is activated when flammable gas detection is registered on the highest level by ceiling or carriage mounted flammable gas detectors. It may also be activated by the highest level ODH alarm.

The Vent Systems include: flammable stack gas dilution, minimum 300 feet per minute duct flow rates to prevent stratification, redundant flow and pressure instrumentation, and compliance with NFPA 497 regulation for venting flammable gases.

Prior to start-up the piping system and detector will be leak-tested and pressure-tested. While on line, a complete resource of documentation for operating procedures, training and maintenance will always be available.

2.3.2.6 Design Basis Accident

As indicated in Table 4-P-3, PHENIX has a flammable gas inventory of over 150 m^3, with 80 m^3 being pure ethane contained in the two RICH vessels. Consideration has been given to scenarios where this gas might be ignited to release much of its stored energy, and to consider the impact of such events on the surrounding facilities, equipment and personnel.

Figure 3-K-1 shows a plan view of the 1008 PHENIX complex. Of interest for this analysis is the collision area centered on the RHIC beam lines, where the detector and RICH vessels are located; the concrete block shield wall separating the detector from the assembly areas; the sparsely populated electronics rack room; the console room where personnel are stationed during RHIC operations; the industrial building shell which separates the rack and console rooms from the assembly area; and the 2 smaller shield walls which separate the tunnel wings from the personnel areas. Before engaging in the DBA analyses, concerns focused on a possible explosion involving the ethane, which could injure personnel in either the assembly or counting house areas. Concerns had been expressed for the safety of personnel, not only from an explosion directly, but also from debris penetrating the industrial building shell.

The analyses described below laid to rest concerns of a major explosion, since the conjunction of large volumes of explosive mixtures coupled with a delayed ignition source are not deemed to be physically achievable. Even in the nonphysical cases investigated, it was found that the major concrete shield wall acted as a blast wall to absorb most of the energy and to protect personnel from missiles. The remote possibility of the collapse of this wall is not ruled out from a secondary pressure rise due to burning of smaller volumes, and hence PHENIX will not fill either RICH vessel with ethane until major activities in the assembly area have subsided, and occupancy is low. When ethane is present in the RICH, access to the IR region will be limited and controlled. The overpressure in the IR due to these pressure rises are nonetheless small, and once vented into the larger volume of the Assembly Area, would not be likely to inflict serious damage on the permeable shell of this structure or threaten personnel in the Counting House. The smaller shield walls on the north and south sides of the IR along the Collider have been shown to survive even the most drastic nonphysical events, and thus no limitation is placed on personnel in the counting house areas.

The analyses did not rule out less violent burns of fractions of the flammable gas inventory. Any significant fire which involves flammable gas is likely to inflict serious damage on the PHENIX experimental equipment and thus to the PHENIX program. The designs of equipment, procedures, and safety systems, which are described in the SAD, are thus intended to mitigate these hazards and also to prevent any possibility of events approaching a DBA class incident. The mitigation of hazards that are described throughout the document including, for example, controls and sensing of flammable gases, inertion of ignition sources, interlocks of possible ignition sources, and forced ventilation of the hall and possible accumulation points. These mitigation strategies were summarized in Table 4-P-1.

The purpose of this section then is to document the independent evaluation (Appendix 28) of the potential explosion hazards, and to establish a Design Basis Accident (DBA) for which safety systems will be implemented. Two DBAs were considered in the analysis. In both cases, it is assumed that all the safety systems fail to detect and respond to the release of combustible gas, and as a result, no action is taken to shut down power to instrumentation which could serve as ignition sources. It is further assumed that the HVAC system has failed so that the gas remains in the IR until ignited.

In the first DBA the full PHENIX inventory of combustibles is released into the Interaction Region (IR), mixed with the existing IR air and then ignited. During flame propagation in the IR, gas is vented from the IR into the Assembly Hall and the North and South Mezzanines. Gas venting mitigates against substantial pressurization of the IR. The results of the analysis indicate that the effects of this DBA would be completely confined to the IR, and that the block shield wall is a stable and effective safety barrier between the fire and the outside world. The analysis also indicates that if a combustible cloud of the correct size and concentration is formed in the IR, and the ignition is timed perfectly, the wall could topple as a result of the ensuing explosion. No scenarios by which such a cloud can form in reality has been identified.

The second DBA analysis explores the effects of the ignition of an explosive mixture of isobutane within the confinement of the Muon magnets. This DBA presumes the release of the full inventory of isobutane from the detectors, and assumes containment of the resulting isobutane-air mixture within the magnet "lampshade" shaped outer shell. The analysis shows that the magnets are sufficiently robust to withstand the overpressure produced by an explosion involving the ignition of the mixture, and thus, the effects of the DBA are limited to the Muon system itself.

Analyses are also performed to determine the response of the three different shielding walls to "theoretical" worst-case explosions. These worst-case explosions are considered theoretical since the underlying assumptions made are non-physical and thus can not be considered the consequence of any credible accident scenario. The results from the analyses should not be used directly to set regulations concerning hazard classifications or occupancy restrictions to any of the areas within 1008 complex. The first analysis deals with an explosion in the IR involving the full combustible gas inventory of PHENIX. Several conservative nonphysical assumptions are made: it is assumed that the combustible gas mixes with just enough air to produce a spherical gas cloud with a mixture composition which yield the highest possible constant volume pressure for an equivalent ethane-air mixture, 2) it is assumed that this unconfined gas cloud explodes producing a similar size cloud of combustion product gases at the constant volume pressure. This high-pressure, high-temperature gas cloud then expands producing a shock wave which interacts with the IR block shield wall and the closest Muon ID plate. It is shown that due to the very short duration of the shock wave loading the block wall does not move by an appreciable amount but is sufficient to tip the Muon plate over towards the back wall. This indicates that even under this theoretical worst case scenario the block wall serves its purpose to shield personnel outside the IR from not only radiation, but also missiles which could be generated from an IR explosion. The analysis also shows that the duration of the combustion product gas depressurization from the IR following the shock loading is sufficiently long that the block wall would collapse. It is worth re-emphasizing that the conditions to achieve this outcome are not practically achievable.

The second analysis looks at the consequences of a theoretical worst case explosion occurring in the north and south mezzanines. For this analysis, it is assumed that the full gas inventory is released in the IR and mixes to form a homogeneous 7% ethane in-air spherical cloud. It is then assumed that the burn occurs at constant pressure displacing the maximum amount of ethane-air into the mezzanines. The nonphysical assumption is then made that this displaced gas mixture then displaces the air in the Mezzanine forming a combustible "slug" of gas. This gas slug then explodes, with no change in volume, generating a pressure equal to the mixture constant volume pressure. The high pressure gas cloud then expands out into the tunnel progressively lowering the pressure in the slug starting at the free end. The most severe pressure time history, corresponding to the location in the mezzanines on the other side of the IR wall, is applied to the entire wall without taking credit for any additional venting generated by the motion of the top of the wall. The results indicate that even under these theoretical worst-case explosions, movement of the block shield walls in the north and south mezzanines are limited to less than 15 cm.

The results of the DBA analysis indicate that the main shield wall will not topple over under realistically achievable conditions. However PHENIX will exercise caution and administratively limit the occupancy of the assembly area once ethane is introduced into the RICH. (The IR will always be declared a controlled area with ethane present.) The justification for this is that there is always some degree of inherent uncertainty in the model concerning scaling of combustion phenomenon, and the possibility of producing a smaller, but higher ethane concentration cloud via some unidentified accident scenario cannot be ruled out. Even if the shield wall did topple, concrete fragments produced by the fall of concrete block onto the concrete floor on a sand base, would not endanger personnel in the counting house, who are separated from the assembly area by the industrial building metal shell. The possibility of the North mezzanine shield block wall collapsing due to any credible accident scenario involving the release and ignition of the PHENIX combustibles in the IR, is so remote as to also not require any limitations on the occupancy of the counting house. Thus under no conditions are personnel in the counting house endangered.

2.3.3 Laser Hazards

The PHENIX experiment uses a Nd:YAG laser as part of the calibration system for its lead scintillator electromagnetic calorimeter, beam-beam and time-of-flight counters. This is a Class IV laser which incorporates two harmonic generators to deliver a power output of 2 watts at 355 nm. The laser and primary beam splitter are housed inside a completely enclosed box which is interlocked with the factory supplied primary safety system of the laser, and is designed to shut down the laser whenever the box is opened. The only light leaving the box is carried out on 9 optical fibers which transport the light to the detectors. These fibers will be labeled on both ends to indicate that they carry laser light and should not be disconnected before disabling the laser. The laser box will be located inside a separate "laser hut" in the PHENIX counting house (Building 1008A) which will be locked at all times and only authorized personnel will be allowed to enter. Authorization to use the laser will require the successful completion of the laboratory approved Laser Safety Training course, along with the required eye exam, and additional training on how to use this particular laser. In addition, a written procedure will be posted outside the laser hut which will specify the rules for the safe operation of the laser in Building 1008A. Laser systems will be designed and operated in accordance with the laser requirements specified in BNL ES&H Standard 2.3.1 and RHIC OPM 5.2.3.1 Lasers, in conjunction with review by the BNL Laser Safety Officer.

2.3.4 Radiation Shielding and Control

Radiation from accelerator beams in the experimental area can be potentially lethal to personnel. Thus, it is vital that the experimental area be vacated before beams are circulated. Further, controlled access to the experimental area will be restricted to personnel trained in the hazards and procedures pertaining to controlled access areas. PHENIX personnel must undergo training in access procedures as established by the RHIC Project and reviewed by the AGS/RHIC Radiation Safety Committee (RSC).

The RHIC Design Criteria in Section 2.5 controls the radiation dose to a Radiation Worker in a high occupancy area to 0.5 rem in the case of a Design Basis Accident fault which is defined as the loss of 50% of the entire beam (at the safety envelope limit of 4 times design intensity) on any magnet and 100% of the beam on any accelerator component near a limiting aperture. Approaches to the buildings at the 8 o'clock Intersection Region (IR) area will be restricted to Radiation Workers.

The shielding near the 8 o'clock IR has been considered in three phases. The first phase is the shield wall Northwest of the IR that separates the tunnel interior from the counting house. The second phase is a wall (which incorporates an emergency escape labyrinth) on the Southwest side of the IR. The gas mixing system is in this area. After the first year of RHIC running, this area will be posted as a Controlled Area.

The final phase of the shielding at 8 o'clock, is the PHENIX shield wall "proper", which separates the IR from the assembly area. This wall incorporates a small movable plug for personnel access, an emergency escape labyrinth, and a large movable door to allow movement of the large elements of the detector between the IR and the assembly area. The design was submitted to the RSC on October 20, 1997 and was approved subject to additional calculations (Appendices 41, 42 and 43). These calculations have been completed without indicating any necessity of change.

The local shielding requirements for the PHENIX detector were calculated and the results discussed in RHIC/DET Note 5 (see Appendix 37).

Q. BERYLLIUM BEAMPIPE

1.0 Overview

This section describes the beampipe and beampipe support system. The Beampipe interfaces with the Collider beampipe which encloses the majority of the remainder of the RHIC ring. Many of the hazards associated with Collider beampipe (vacuum loading, bakeout, etc.) are to be covered in the Vacuum System Safety documentation not be covered here.

1.1 Description of STAR Beampipe

The beampipe is a thin walled cylindrical tube approximately 8.1m long and 3 inches (8 cm) in diameter. It is made up of a "low Z", 1 mm wall, beryllium center section approximately 1.5 m long, with 1.25mm wall aluminum extensions EB welded to either side. At the ends of the aluminum extensions, there are aluminum/stainless "conflat" type flanges that get bolted to the more convectional stainless steel RHIC beampipe components at either end. The STAR beampipe and some of the RHIC beampipe components are supported by cantilever supports hung from the 6 O'Clock WAH walls.

1.2 Description of PHENIX Beampipe

The PHENIX beampipe is a thin-walled cylindrical tube with overall length of 205.5". It is made up from a central 59" long beryllium section formed from 0.04" thick rolled and seam brazed sheet. The central beryllium section is then brazed to stainless steel end sections which are in turn welded to standard 4.5" conflat flanges. The flanges are bolted to the corresponding flanges on the

RHIC accelerator beamtube. The PHENIX tube is supported from the flanges and also within the central magnet by low mass "ring and radial fiber" supports.

2.0 Safety Analysis

2.1 Hazards

2.1.1 Mechanical Hazards

The mechanical hazards associated with the Experimental Beampipe relate to installation of the beampipe and the support structure.

Although the beampipe is long, small in diameter and thin-walled, its mass is low so that the design is not stress limited. The limiting factor in the design of the beampipe and the support system is to limit deflection. This is accomplished through a series of supports along the beampipe. Stresses induced by thermal strains during bakeout will be greatly reduced by the use of in-line bellows designed for this application.

When the pipe is transported it must be supported such that midspan deflections are kept below a few inches. It should also not be exposed to localized impacts such as dropped tools or bumping that would cause dents or a brittle failure (cracking). This will be accomplished by leaving the pipe in its shipping crate right up until the point that it is ready to be slid into the detector and then by using extreme care during this operation.

The beampipe supports outside of the detector volume are made up of standard structural steel I's and angle's. Maximum deflections due to gravity (their own weight plus that of the beampipe) are low (e.g., less than 0.2 inches [5 mm]). The stresses are correspondingly very low because the supports are designed for minimum beampipe deflection (e.g., <1000psi).

The beampipe support system inside the detector (closest to the IP) will be of lower mass for physics reasons. This system will utilize multi-filament wire or fiber in a "spider" type fashion (several radial wires equally spaced over 360 degrees). Because the weight supported by this part of the system is so low (a few pounds or less), the stresses will likely by very low also for any commercially available wire/fiber diameter.

2.1.2 Material Hazards

Because beryllium is toxic when inhaled as a respirable dust, great care is taken during fabrication at the vendor. However, the beampipe as delivered has a epoxy coating on the outside diameter and is UHV cleaned on the inside. The specification for fabrication required that these coating and cleaning operations eliminate the possibility of fine Be dust and thus the particulate breathing hazards to personnel.

Other fine particulate hazards would be caused by brittle failure of the pipe. Two such cases can be envisioned. One would be something small such as a wrench or bolt being dropped and would result in a piece or several pieces of beryllium falling out. It is envisioned that a very small quantity of beryllium particulate would be generated, but not as respirable particle sizes. If the failure were caused by a much larger item falling through the beampipe, greater quantities of particulate could be generated. In either case, it is not expected that the material would be of respirable particle size and thus will not create an airborne hazard. In the event of a beryllium fracture, a proper hazardous material cleanup, with assistance from experts in the S&H Services Division, will be conducted. The need for a supervised cleanup shall be required in the Vacuum System Operations Procedures.